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Groundwater Remedial Investigation Report

Volume 1: Technical Report

Reynolds Metals Company
TROUTDALE FACILITY

CH2MHILL

June 1999

PDX18226.DOC

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Abbreviations and Acronyms

bgs	below ground surface
BLA	Blue Lake Aquifer
BPA	Bonneville Power Administration
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfs	cubic feet per second
CL	Company Lake
cm/sec	centimeters per second
COE	U.S. Army Corps of Engineers
COP	City of Portland
CRBG	Columbia River Basalt Group
CSS	*Current Situations Summary*
CU1	Confining Unit 1
CU2	Confining Unit 2
DCE	dichloroethene
DEQ	Oregon Department of Environmental Quality
EE/CA	Engineering Evaluation/Cost Analysis
EPA	U.S. Environmental Protection Agency
EPL	east potliner
ESP	electrostatic precipitator
FS	feasibility study
ft/ft	feet per foot
gpd	gallons per day
gpm	gallons per minute
gpm/ft	gallons per minute per foot
GS&G	Gresham Sand and Gravel
MCL	maximum contaminant level
MF	mixing factor
mgd	million gallons per day
mg/kg	milligram(s) per kilogram
mg/L	milligram(s) per liter
MSL	mean sea level
NGVD	National Geodetic Vertical Datum
NLF	north landfill
NPDES	National Pollutant Discharge Elimination System
ODEQ	Oregon Department of Environmental Quality
ORS	Oregon Revised Statute
OWRD	Oregon Water Resources Department
PAH	polynuclear aromatic hydrocarbon
PCB	polycyclic biphenyl
PCE	tetrachlorethene
PWB	Portland Water Bureau
R3E	Range 3 East

RD/RA	remedial design/remedial action
RI	remedial investigation
RMC	Reynolds Metals Company
ROD	Record of Decision
SAP	*Sampling and Analysis Plan*
SGA	Sand and Gravel Aquifer
SLF	south landfill
SVOC	semivolatile organic compound
SY	scrap yard
T1N	Township 1 North
T1S	Township 1 South
TGA	Troutdale Gravel Aquifer
TSA	Troutdale Sandstone Aquifer
UGS	upper gray sand
USA	Unconsolidated Sedimentary Aquifer
USGS	U.S. Geological Survey
VOC	volatile organic compound

SECTION 1

Introduction

SECTION 1
Introduction

This document presents the results of the groundwater investigation and evaluation conducted from 1994 to 1999 as part of the remedial investigation (RI) and feasibility study (FS) for the Reynolds Metals Company (RMC) facility at Troutdale, Oregon (see Figure 1-1 for a map of the vicinity). The RI/FS was conducted under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

The site RI was conducted in four related programs focusing on:

- Soil and debris areas
- Wastewater discharge areas
- Surface water and sediment areas
- Sitewide groundwater

The results of the RI for nongroundwater media are presented in a separate document titled Nongroundwater Remedial Investigation Report (CH2M HILL, In Progress).

1.1 Organization of This Report

Most of the groundwater data collected for this project were presented in earlier documents shortly after collection. The goals of this report are to:

- Summarize the results of the groundwater investigation
- Present a conceptual hydrogeologic model of the site
- Present conclusions drawn from the data and from the numeric groundwater model developed for the site
- Indicate where more detailed information can be found in previous documents and in companion documents being prepared concurrently

This introductory section includes a brief site description and project history to provide a context for the groundwater investigation and results.

Section 2 summarizes the subsurface investigations that have been conducted at the site. Detailed results of these investigations have been presented in the documents cited in Section 2, and overall results of the investigations are presented in Sections 3 and 4 of this report.

Section 3 describes the physical setting for groundwater at the site and summarizes the development of the conceptual hydrogeologic model. More information on the numeric model developed for this project is presented in Technical Memorandum No. GW-20: Development of an Updated Hydrogeologic Conceptual Model and a Numerical Groundwater Flow Model at RMC-Troutdale (CH2M HILL, In Progress).

Section 4 summarizes the nature and extent of chemical constituents in the groundwater based on the sampling and analysis conducted during the project.

Section 5 presents a discussion of the fate and transport of fluoride, the only constituent prevalent in groundwater at concentrations that exceed the maximum contaminant level (MCL).

Appendixes A through G are located in Volume 3 of this report. A list of appendixes follows:

- Appendix A: South Plant Groundwater/Surface Water Interaction
- Appendix B: Summary of 1998 Field Data Collection at South Landfill, Scrap Yard, and East Potliner
- Appendix C: Onsite Well Logs
- Appendix D: Oregon Water Resources Department Well Logs for Offsite Water Supply Wells
- Appendix E: Summary of Analytical Data
- Appendix F: Water Level Response at the RMC Site to Pumping at the City of Portland's Columbia South Shore Wellfield
- Appendix G: Fluoride Transport Assessment at the RMC Site

1.2 Purpose of the Groundwater Remedial Investigation

The purpose of the groundwater remedial investigation has been to collect sufficient data to determine whether remedial action is needed and, if so, to develop and evaluate appropriate remedial alternatives. In support of this purpose, the RI has conducted field activities, laboratory analyses, treatability bench testing, risk assessment, numerical groundwater flow modeling, and extensive data evaluation and interpretation.

The RMC groundwater remedial investigation was based on the following three guidelines:

1. The groundwater investigation was conducted on a sitewide basis rather than for separate soil and debris areas or other subareas. The overall goal of the groundwater program is a cohesive, consistent, cost-effective sitewide remedy. To achieve this goal, it has been necessary to understand the hydrogeology sitewide.
2. Emphasis was placed on evaluating whether constituents from the facility had migrated downgradient toward current potential receptors.
3. The impact of potential source areas on groundwater was evaluated first from actual groundwater sampling results and refined by soils data, rather than looking first at soils data and trying to predict the effect on groundwater.

These guidelines are stated on page 2-3 of the *Draft Groundwater Addendum to the RI/FS Work Plan* (CH2M HILL, June 2, 1997).

1.3 Site Description

The RMC Troutdale facility is a primary aluminum reduction plant where alumina is reduced to aluminum. The plant is located approximately 20 miles east of Portland, Oregon, and 1.25 miles north of the City of Troutdale, Oregon, at the confluence of the Columbia and Sandy Rivers. RMC owns the 80.25-acre plant area and approximately 715 acres of surrounding rural land (Figure 1-1).

1.3.1 Physical Features

The RMC property is bordered by the Columbia River to the north, the Sandy River to the east, the Troutdale Airport to the south, and Salmon Creek to the west. Figure 1-2 displays key site features. A U.S. Army Corps of Engineers (COE) flood control dike runs approximately east-west through the northern portion of the RMC property, then turns south at the eastern property boundary. The Troutdale substation, located within the plant boundary, is owned and operated by the Bonneville Power Administration (BPA).

The site topography is generally flat (20 feet to 30 feet elevation), with some minor relief toward the north and northeast.

Plant process buildings are located in the central portion of the site (see Figure 1-2 for area and building locations). Site areas north and east of the dike are within the 100-year floodplain; some areas also lie within the 10-year floodplain. The eastern part of the plant site inside the dike consists of open fields and waste storage areas. Storage areas inside the dike include scrap yard, east potliner, cryolite ponds, and south landfill. North landfill is the only storage area located outside the dike. There are some wooded areas close to the plant fence. The eastern part of the plant site outside the dike is a generally flat, sandy area with some vegetation cover.

North of the flood control dike, the topography is mostly flat, slopes gently toward the river, and is transected by numerous small east-west-trending drainages. The area is wooded, with relatively heavy vegetation in most areas. There is a beach on the Columbia River along the northern part of the property that is used occasionally for recreation.

The wastewater discharge areas comprise South Ditch and Company Lake, which are part of the permitted National Pollutant Discharge Elimination System (NPDES) wastewater facility. Wastewater treatment plant effluent is discharged into South Ditch, then pumped through a buried pipeline into Company Lake. Company Lake is used as a wastewater treatment pond for equalizing flow and concentrations under the facility's NPDES permit. The pond discharges through an outfall ditch into the Columbia River. The south wetlands area (including Building 97 subarea and West Drainage), located in the southern portion of the site, was used by the U.S. Government as a settling basin for wastewater shortly after the plant opened in 1941. This practice was continued by RMC until sometime around 1965. The area has since reverted to a wetland of predominantly reed canarygrass.

1.3.2 Climate

The study area is characterized by a mild, temperate marine climate with moderately warm, dry summers and wet winters. The average annual precipitation in the area is approximately 37 inches per year. Forty to 50 percent of the total annual precipitation falls in

January and February. The average daily maximum temperature is 62°F, and the average daily minimum temperature is 44°F (Ecology and Environment, Inc., 1991). RMC staff have indicated that the prevailing winds near the plant site are from the south and southwest in summer, and from the east in winter.

1.3.3 Land Use

The RMC property south of the flood control dike is currently zoned Urban Future (UF-20) and Urban Heavy Manufacturing (HM). Both of these zoning designations allow community service uses under the provisions of Multnomah County Code (MCC) 11.15.7005-30 as conditional use. The property north of the flood control dike is zoned UF-20, with overlays for Significant Environmental Concern (SEC) and Flood Fringe (FF).

The surrounding area to the west and south of RMC-owned land is mainly used for agricultural and commercial purposes. The Port of Portland's Troutdale Airport is located approximately 0.25 mile south of the RMC property.

1.3.4 Water Use

Onsite deep production wells [between approximately 250 and 625 feet below ground surface (bgs)] supply process water and drinking water for workers at the RMC facility. Of the 18 deep production wells, only a few are still active. In some areas of the plant, bottled water, provided at the request of employees, is available for drinking.

A survey of local groundwater use was conducted; the results are presented in Section 3.4.

1.3.5 Definition of Water-Bearing Zones

The unconsolidated sediments within the uppermost regional groundwater system beneath the RMC facility have been subdivided into four water-bearing zones since the investigations started in 1994. The four zones are defined by the site stratigraphy and the depths at which monitoring wells have been constructed. These four zones and their terminology are:

- **Silt Unit.** Where present, the silt unit extends from ground surface to approximately 30 feet below ground surface (bgs). The silt unit is also referred to as the silt in this report.
- **Upper Gray Sand (UGS).** The UGS extends to a depth of approximately 50 feet bgs. It is present at ground surface north of the flood control dike and lies beneath the silt unit south of the dike.
- **Intermediate Sand.** The intermediate sand extends from the base of the UGS to a depth of 100 feet bgs and is also referred to as the intermediate-depth zone in this report.
- **Deep Sand/Gravel.** The deep sand/gravel extends from the base of the intermediate sand to a depth of 200 feet bgs and is also referred to as the deep zone in this report.

1.4 Project History

The current RI/FS began in September 1995 with a Consent Order signed by the U.S. Environmental Protection Agency (EPA) and RMC. Other investigations, summarized in

Section 2 of this report, preceded EPA involvement at the site. The largest of these efforts was the Removal Site Assessment in summer 1994, during which soil sampling was conducted and test pits excavated to classify waste materials for disposal.

Before and during the RI/FS, RMC conducted early actions to:

- Remove wastes at east potliner and the cryolite ponds
- Remove PCB-contaminated soil from the casthouse area
- Remove sediments from the bakehouse sumps and modify the sumps
- Dredge portions of east South Ditch near east potliner
- Restrict access to areas previously accessible to the public, primarily north of the flood control dike (installed fencing and signs)
- Install a new containment system for the wet electrostatic precipitator
- Decommission wells and well points no longer in use

Investigations in the soil and debris areas, wastewater discharge areas, and surface water and sediment areas have been concurrent with the groundwater investigation. These investigations are now complete. The remedial investigation for nongroundwater media is being summarized in a separate document. A baseline risk assessment is expected to be completed by summer 1999. A focused feasibility study will address risks identified by the investigations and risk assessment and will be submitted to EPA following submittal of the RI documents and the baseline risk assessment documents.

1.5 Conclusions

RMC has conducted numerous groundwater investigations and evaluations since 1994. Approximately 169 monitoring wells, piezometers, temporary well points, and Geoprobes® have been installed by RMC during the past five years. RMC has performed 17 quarterly monitoring events on selected wells, collecting samples from the 93 monitoring wells a total of 598 times. The data collected during this extensive program has facilitated an understanding of the site hydrogeology and groundwater quality, as well as an understanding of fluoride transport in groundwater.

Summarized below are the conclusions presented in this RI report.

1.5.1 Conceptual Hydrogeologic Model

The hydrogeology of the RMC facility and surrounding areas is characterized below.

- The facility is located in the eastern part of the Portland structural basin. The facility is underlain by two regional aquifer systems [the Unconsolidated Sedimentary Aquifer (USA) and the deeper Sand and Gravel Aquifer (SGA)]. These unconsolidated sediments are underlain by consolidated materials associated with the Older Rock Unit, which lies at depths ranging from near ground surface in the Columbia River to 550 feet beneath the RMC facility and 800 feet or greater south of the facility.

- The site-specific hydrostratigraphy is as follows:
  - A surficial unit called the silt unit is present south of the Corps of Engineers flood control dike. In this area, the silt unit consists of a surficial overlying sand horizon and an underlying silt horizon. The overlying sand is typically less than 10 feet thick. The silt horizon is typically 20 feet thick, except at scrap yard where it is as little as 8 feet thick.
  - The silt unit is underlain by well-sorted sands. These sands are subdivided into the upper gray sand (UGS), the intermediate sand, and the deep sand. These sands are present to depths of 400 feet in the southern portion of the site and approximately 175 feet or less in the remainder of the site.
  - The materials underlying the well-sorted sands consist of interbedded sand and gravel layers with occasional silt and sandy silt layers. In places, the well-sorted sands are separated from the interbedded materials by a distinct layer of silt or sandy silt.
- Groundwater flow patterns are as follows:
  - Flow patterns within the silt unit are controlled primarily by precipitation infiltration and the influences of localized surface water features (specifically South Ditch, south wetlands, and Salmon Creek, which are localized discharge/recharge points for groundwater). Silt unit groundwater generally moves vertically into the UGS or horizontally over limited distances toward these surface water features.
  - The ambient groundwater flow direction in the UGS and deeper zones beneath the RMC facility is generally from the south and southeast to the north and northwest, with groundwater discharging to the Columbia and Sandy Rivers. However, groundwater flow patterns are also strongly controlled by pumping from the RMC production wells and (in localized areas) by surface water features (particularly the Columbia River, the Sandy River, and Company Lake).
- The horizontal hydraulic conductivities of the hydrogeologic units beneath the RMC facility are estimated to be:
  - Silt unit: 1 to 2 ft/day
  - UGS: 2 to 35 ft/day
  - Intermediate sand: 100 to 150 ft/day or higher
  - Deep sand: 75 to 175 ft/day
- Well construction records and water rights records on file at the Oregon Water Resources Department (OWRD) indicate that offsite uses of groundwater occur in areas within one mile of the plant. For this search area, records were found for 37 wells, in addition to the RMC production wells. These wells withdraw groundwater from the USA and (in areas south of the USA's southern boundary) from other aquifer zones. Additional queries of the OWRD database for surface water permit data showed no points of diversion from the Columbia and Sandy Rivers in this same search area.

1.5.2 Nature and Extent of Constituents of Potential Concern

Background concentrations and constituents of potential concern in groundwater will be identified in the baseline risk assessment (to be completed in the summer of 1999). A determination of remedial goals for groundwater will be made in the Record of Decision (ROD). In the meantime, MCLs have been used as a benchmark for preliminary assessment of groundwater conditions at the site. Pending the baseline risk assessment and final cleanup goals, fluoride is considered the predominant constituent of potential concern because of its distribution and presence above the MCL (4 mg/L).

Other than fluoride, only a few constituents have exceeded the MCL. Between 1994 and 1997, amenable cyanide was detected above the MCL at nine wells, but in 1997 it was detected at just one well. Six metals were detected above the MCL between 1997 and 1998. Toluene has been detected in some deep wells and is believed to originate from a source upgradient of the site. Volatile organic compounds, or VOCs (1,1-dichloroethene and tetrachloroethene) detected above the MCL are limited to an area near the northwest corner of the bakehouse. With few exceptions, all of the above constituents exceeding the MCL are co-located with fluoride.

- Based on the horizontal and vertical distribution of fluoride, the following conclusions can be drawn.
  - Areas where fluoride concentrations exceed 4 mg/L primarily include north landfill, east potliner, scrap yard, Company Lake, and south landfill. However, groundwater fluoride concentrations exceeding 100 mg/L are limited to relatively localized areas, primarily in the silt unit in scrap yard, south landfill, and east potliner.
  - Company Lake appears to be a source of fluoride to groundwater. The presence of elevated fluoride concentrations in the intermediate-depth sand and deep sand/gravel units south of Company Lake is likely due to the influence of onsite production well pumping rather than the migration of fluoride from soil and debris areas farther south.
  - At north landfill, elevated fluoride concentrations in the UGS are centered around MW09-030 (31.5 mg/L). Surrounding Geoprobe and monitoring well fluoride data range between 0.29 and 15 mg/L and indicate fluoride is not discharging to the river from north landfill.
  - Scrap yard appears to be the source of fluoride in the intermediate-depth sand and deep sand/gravel units lying between scrap yard and production wells. Elevated levels of fluoride in groundwater in the silt unit and UGS at south landfill and east potliner do not appear to contribute to this plume.
  - At south landfill, the silt unit and the UGS contain elevated concentrations of fluoride. However, detections above the MCL in the UGS are concentrated in a localized area (at Geoprobe GP59). Other south landfill Geoprobe fluoride concentrations are below those observed elsewhere in the UGS (that is, lower than at scrap yard and east potliner). The absence of fluoride in the intermediate-depth sands at and downgradient of south landfill is consistent with this observation.

  - Fluoride movement in the silt unit appears to be vertically downward rather than horizontal. This observation is suggested by the limited extent of fluoride in the silt unit compared with the underlying units.

- Six metals (antimony, arsenic, beryllium, chromium, lead, and nickel) were detected above MCLs at the RMC site between 1994 and 1998. The 1998 distribution of metals above the MCL suggests that east potliner, scrap yard, and south landfill are potential source areas.

- In 1997, amenable cyanide was detected above the MCL at only one well location. Amenable cyanide analysis was not included in the 1998 groundwater monitoring program.

- The occurrence of two VOCs (1,1-dichloroethene and tetrachloroethene) in exceedance of MCLs is limited to two shallow wells located near the northwest corner of the bake-house.

1.5.3 Fluoride Migration in Groundwater

Migration of fluoride in groundwater at the RMC facility is summarized below.

- The principal control on fluoride transport in groundwater has been the historical use of the RMC production wells. To a lesser degree, ambient groundwater flow patterns have also affected the extent of fluoride in groundwater. The portion of the fluoride plume that is present in the intermediate and deep zones appears to be centered around the RMC production wells and is the result of fluoride loading from scrap yard and Company Lake and pumping influences from the production wells. Specifically:

  - Scrap yard and Company Lake contribute fluoride from areas south and north of the production wells, respectively. The presence of fluoride between Company Lake and the production wells is the result of fluoride loading from Company Lake to intermediate-zone groundwater and migration of intermediate-zone groundwater towards the production wells due to pumping. Because of the historical use of the production wells, fluoride presence between Company Lake and the wells does not appear to be the result of groundwater migration from the scrap yard past the production wells.

  - The presence of the fluoride plume in the intermediate and deep zones is attributable to the natural downward gradients at scrap yard and Company Lake, plus the creation of strong downward gradients by pumping of the RMC production wells.

  - A long-term period of inactivity at the RMC wellfield would cause changes in groundwater flow directions, which in turn would cause changes in fluoride migration patterns. Under such a scenario, groundwater possibly containing fluoride from the three south plant soil and debris areas would migrate in a northerly and northeasterly direction towards the Sandy River and the Sandy River bar (which occupies the Columbia River at the mouth of the Sandy River).

  - Groundwater modeling analyses indicate that travel times from scrap yard (in the UGS) to the production wells under historical pumping conditions have been between 10 and 15 years (assuming an effective porosity of 0.20 for the aquifer system). Under a sustained period of no pumping, the modeling analyses suggest that groundwater travel times from the UGS at scrap yard to the Sandy River would be on the order of 30 to 40 years.

- Pumping of RMC wells and wells owned by the City of Portland in the Blue Lake Aquifer (BLA) is unlikely to influence groundwater flow directions on the RMC facility or in the BLA. This is indicated by continuous recording of groundwater levels and river stages during a multiwell aquifer test of four RMC production wells during October 1995, as well as a 27-day period of pumping from the BLA (at an average rate of 20,000 gallons per minute) during late 1995. Consequently, fluoride beneath the RMC facility is not expected to migrate west towards the BLA due to either RMC or BLA pumping activities.

- Soil and groundwater concentration data in the silt unit and the UGS indicate that the migration of fluoride into the UGS and the intermediate zone is controlled by the permeability and thickness of the silt unit. Specific observations are:

  - The highest soil fluoride concentrations in the silt unit at scrap yard were measured in the surficial debris layer and the underlying sand layer (situated just above the silt horizon). In the silt horizon, soil concentrations are only slightly higher than background levels, whereas groundwater concentrations are elevated, which indicates that the silt unit is not a significant contributor of fluoride to groundwater.

  - In contrast, at east potliner and south landfill, elevated soil concentrations coincide more closely in location and depth with elevated groundwater concentrations. The distribution of fluoride concentrations in groundwater at south landfill indicates that fluoride concentrations in silt unit groundwater are reduced by a factor of approximately seven upon infiltrating into the underlying UGS.

  - The occurrence of fluoride in the UGS is correlated with the silt unit permeability and inversely correlated with the silt unit thickness. Of the three soil and debris areas in the south plant, south landfill shows the lowest concentrations of fluoride in the UGS, the smallest areal extent of fluoride in the UGS, the greatest silt unit thickness (20 feet), and the lowest vertical permeability that has been measured in site soils (9.8×10^{-8} cm/sec). In contrast, scrap yard shows the highest fluoride concentrations in the UGS, the largest areal extent of fluoride in the UGS, and the thinnest (8 feet) and most permeable (2×10^{-6} cm/sec) silt unit.

- Fluoride concentration data in the RMC production wells indicate that fluoride concentration trends in individual production wells and in the tap water are directly related to the combined pumping rate of the wellfield, as well as the rates and durations of pumping at individual production wells. The data indicate that increased pumping of the shallowest production wells (PW07 and PW08) during 1997 and early 1998 induced downward migration of fluoride, resulting in higher concentrations in the intermediate-zone and deep-zone monitoring wells at MW33 followed by higher concentrations in the production wells and tap water.

- Quantitative evaluations of fluoride adsorption and desorption processes have been performed to identify areas where current soil fluoride concentrations are sufficiently elevated that the soils alone could sustain groundwater concentrations exceeding the

MCL (irrespective of the concentration of groundwater migrating from an adjoining upgradient area). These evaluations indicate that existing soil concentrations of fluoride in the intermediate zone and in portions of the UGS are unlikely to sustain groundwater concentrations of fluoride that are as high as those currently seen in the fluoride plume in groundwater. However, adsorbed fluoride concentrations in some UGS soils and some shallower site soils could sustain groundwater concentrations in those zones at levels exceeding the MCL. These conclusions also indicate that fluoride concentrations on site soils are not expected to cause increases in fluoride concentrations in groundwater above historically observed levels.

SECTION 2

Groundwater Remedial Investigation and Evaluation

SECTION 2

Groundwater Remedial Investigation and Evaluation

2.1 Introduction

This section summarizes the work conducted from summer 1994 to the present in support of the remedial investigation purposes presented in Section 1. This work has included:

- Installation of 93 monitoring wells, sampled a total of 598 times
- Installation of 22 piezometers for water level measurements and subsurface hydrogeologic information
- Installation of 57 Geoprobes, from which 491 samples were collected
- Installation, sampling, and subsequent decommissioning of 12 temporary well points
- Collection of samples from 13 production wells and 4 offsite wells
- Three separate series of aquifer tests—slug tests, short-term tests, and long-term tests
- Water level elevation data measured at all wells monthly from July 1994 to March 1998, after which time measurements were taken quarterly
- Laboratory analyses: a total of 2,118 analyses for fluoride, metals, general chemistry, cyanide, chromium, volatile organic compounds (VOCs), polynuclear aromatic hydrocarbons (PAHs), semivolatile organic compounds (SVOCs), and polycyclic biphenyls (PCBs)
- Treatability bench testing for precipitation of fluoride from extracted groundwater
- Area water use survey
- Development of a numerical groundwater flow model
- Data evaluation and interpretation

One of the early actions conducted during the course of the RI was the decommissioning of nine plant production wells no longer in use. This activity will be described in a document to be submitted to EPA titled Production Well Decommissioning Final Report (CH2M HILL, In Progress). In addition, the Bakehouse sumps removal action was conducted in a phased approach between May 1995 and November 1997. This removal action included decommissioning of temporary well points at the Bakehouse, rebuilding the sumps to provide a surface seal, and getting all of the sump pumps operational. Geoprobes, piezometers, temporary well points, and selected monitoring wells have also been removed. Figure 2-1 shows the locations of these decommissioned boreholes.

Most of this work has previously been described and the results presented in other documents that have been submitted to EPA. The purpose of this section is to present an overall project summary without repeating previously presented material, while indicating where the full information can be found.

Certain documents are referred to in this report for the first time [for example, Technical Memorandum No. GW-20: Development of an Updated Hydrogeologic Conceptual Model and a Numerical Groundwater Flow Model at RMC-Troutdale (CH2M HILL, In Progress)]. This section refers the reader to such documents and to details and results presented in other sections and appendixes of this report.

2.2 Chronology of Groundwater Remedial Investigation

During the early years of the project the most critical issue was to assess whether constituents from plant activities had entered the groundwater and migrated offsite, either to nearby potential human or ecological receptors or into the Columbia or Sandy Rivers, and if so whether the migration posed a critical risk.

Once it was established that no critical risk had been created, the focus of the groundwater RI shifted to investigating the nature and extent of chemical constituents within the RMC plant, identifying sources, and developing a better understanding of fate and transport through groundwater migration.

The following paragraphs provide a narrative description of the progression of groundwater activities year by year. The project chronology is presented in more detail in Table 2-1.

1994 As part of the Removal Site Assessment [*Removal Site Assessment Report, Volume 1* (CH2M HILL, January 1995)], twelve shallow monitoring wells were installed near the site perimeter both upgradient (for background water quality) and downgradient of the central site facility. These wells provided information about the extent of fluoride migration and about horizontal groundwater flow directions.

1995 An additional 30 shallow monitoring wells were installed in the interior of the site in areas considered potential sources of fluoride. Groundwater monitoring continued. [See the *Annual Groundwater Monitoring Report: August 1994-August 1995* (CH2M HILL, February 8, 1996).]

Well PW15 was decommissioned (March 1995).

Early actions were begun at east potliner and the cryolite ponds to remove waste materials and shallow soils that were potential sources of fluoride to groundwater.

1996 Twenty-five deep and intermediate-depth monitoring wells were installed near existing shallow wells to determine the vertical distribution of constituents and vertical gradients (existing well MW02-024 was deepened to MW02-034). Thirteen additional shallow monitoring wells were installed in October, November, and December 1996. Groundwater monitoring continued quarterly. [See *Technical Memorandum No. GW-9: November 1996 Quarterly Groundwater Monitoring Results*

(CH2M HILL, January 1997) and *Technical Memorandum No. GW-10: February 1997 Quarterly Groundwater Monitoring Results* (CH2M HILL, June 1997).]

Five deep site production wells (PW04, PW06, PW11, PW12, and PW17) were decommissioned between April and June 1996.

1997 In June 1997, 14 shallow groundwater monitoring wells were installed around the bakehouse to assess the water quality effects of bakehouse activities on shallow groundwater and to provide additional information on flow directions and hydraulic gradients. Six shallow piezometers were installed in fall 1997 to assess groundwater elevations near the bakehouse.

During summer 1997, 48 Geoprobes were installed, 22 along the Columbia and Sandy Rivers and 26 within the site interior, to better understand the nature and extent of constituents in groundwater and to evaluate groundwater and surface water interactions at Company Lake. [See *Technical Memorandum No. GW-15: 1997 Groundwater Field Summary* (CH2M HILL, May 8, 1998) and *Technical Memorandum No. GW-18: August 1998 Groundwater Monitoring Results* (CH2M HILL, December 30, 1998).] From June to October, 10 additional monitoring wells were installed as a result of the Geoprobe investigation. Quarterly groundwater monitoring continued. See the following documents for February, May, August, and November 1997 monitoring results:

- *Technical Memorandum No. GW-10: February 1997 Quarterly Groundwater Monitoring Results*
- *Technical Memorandum No. GW-11: May 1997 Quarterly Groundwater Sampling Event* (CH2M HILL, October 30, 1997)
- *Technical Memorandum No. GW-12: August 1997 Quarterly Groundwater Monitoring Results* (CH2M HILL, December 18, 1997)
- *Technical Memorandum No. GW-13: November 1997 Quarterly Groundwater Monitoring Results* (CH2M HILL, February 13, 1998)

Three series of aquifer tests were conducted in 1997:

- January to March, slug tests on 35 deep, shallow, and intermediate monitoring wells
- February to April, short-term (5 to 8 hours) tests at 12 monitoring wells
- September, month-long pumping by Fairview Farms Well No. 4 and two nearby RMC production wells

See *Technical Memorandum No. GW-16: Aquifer Tests Results, RMC-Troutdale* (CH2M HILL, July 23, 1998) for more information.

1998 In May 1998, wells that had been installed in 1997 were sampled to provide four consecutive quarters of sampling. Other wells were sampled only in February and August. No additional wells were installed in 1998.

See the following documents for February, May, and August 1998 monitoring results:

- *Technical Memorandum No. GW-14: February 1998 Groundwater Monitoring Results* (CH2M HILL, May 26, 1998)
- *Technical Memorandum No. GW-17: May 1998 Groundwater Monitoring Results* (CH2M HILL, July 24, 1998)
- *Technical Memorandum No. GW-18: August 1998 Groundwater Monitoring Results*

Twenty Geoprobe hollow stem augers (HSAs) were installed in scrap yard, south landfill, and east potliner to assess distribution of fluoride in soil and groundwater. Nine of these were specifically installed to measure fluoride in groundwater. (Refer to Appendix B of Volume 3 for details.)

Two deep site production wells (PW09 and PW14) were decommissioned during summer 1998.

1999 No additional wells were installed in 1999. Groundwater monitoring was conducted in February and is planned for August 1999. Data results from the February 1999 sampling event were not available for inclusion in this document.

2.3 Groundwater Monitoring Program

Groundwater monitoring began in July 1994 and continued quarterly through 1997. In 1998 the frequency was reduced to twice a year. By 1998, an evaluation of the sampling results indicated that not all wells continued to require frequent monitoring. In February and August 1998, 55 of 93 available wells were sampled.

The groundwater monitoring program is summarized in Tables 2-2 through 2-4. Table 2-2 lists the groundwater monitoring wells and other wells that were sampled for the project, showing the location, installation date, depth, and hydrogeologic unit. Figure 2-2 shows the location of these wells. Table 2-3 is a well by well summary of sampling events from July 1994 through August 1998. Table 2-4 summarizes the analyte lists for these sampling events.

2.4 Water Use Survey

Local groundwater use was surveyed to identify current groundwater users who might potentially be receptors of constituents migrating in groundwater from the RMC facility. The results of this survey are reported in Section 3 of this document.

2.5 Background Water Quality Investigation

A background investigation was conducted at the RMC Troutdale site for the purpose of determining chemical concentrations in groundwater. Groundwater quality data representative of background conditions (upgradient of the site) were evaluated for two onsite locations (MW-03 and MW-05), six City of Troutdale wells, and more than 40 monitoring wells from the City of Portland Water Bureau. Groundwater samples were collected for site upgradient monitoring wells between 1994 and 1997 and primarily analyzed for total and dissolved metals and volatile organic compounds. Water quality data were obtained from the Cities of Troutdale and Portland. The results of this background evaluation are presented in the document titled Draft Baseline Risk Assessment for Groundwater (CH2M HILL, In Progress).

2.6 Data Evaluation and Interpretation

The data collected during the activities described above supported numerous data evaluations and extensive technical interpretation to gain an understanding of groundwater flow, groundwater/surface water interaction, and the transport of chemical constituents, especially fluoride. The following list identifies major evaluation and interpretation activities and indicates where detailed information on each can be found.

2.6.1 Numerical Groundwater Flow Model Development

One of the major activities in 1997 and 1998 was the development of a groundwater flow model for the Troutdale site and its immediate surroundings. The purpose of this model is to validate an understanding of site hydrogeology and to provide confidence that the system will behave as predicted in the future, both with no remedial action and under potential remedial alternatives. Section 3 of this document presents the conceptual hydrogeologic model. A separate document (Technical Memorandum No. GW-20: Development of an Updated Hydrogeologic Conceptual Model and a Numerical Groundwater Flow Model at RMC-Troutdale) will provide the technical details for the numerical model.

2.6.2 Groundwater/Surface Water Interactions

Surface water in the following locations is hydraulically connected with groundwater at the site:

- Columbia River
- Sandy River
- Company Lake
- East Lake
- South Ditch
- West Drainage
- South Wetlands
- Salmon Creek

Groundwater/surface water interactions at the site tend to be complex and variable. During the course of the project, the groundwater/surface water interactions at the site were evaluated to assess the potential for migration of contaminants between these two media and are presented in terms of the conceptual hydrogeologic model in Section 3 of this document.

Table 2-5 summarizes the various groundwater/surface water evaluations conducted between 1994 and 1999 and indicates where additional details can be found.

2.6.3 Hydraulic Communication with City of Portland Wells

The City of Portland has a water supply wellfield west of the Troutdale facility. RMC investigated whether the plant production wells are in hydraulic connection with the City of Portland wells. This evaluation is presented in Appendix F of this document (Volume 3).

2.6.4 Effects of River Fluctuations on Site Groundwater

Groundwater at the site discharges to the Columbia and Sandy Rivers. RMC investigated the influence of river elevations on site groundwater level elevations. The results are presented in Appendix G of this document (Volume 3).

2.6.5 Effect of Groundwater Discharge on Constituent Concentrations in Columbia and Sandy Rivers

The potential for constituents to migrate via groundwater into the rivers and affect aquatic biota was investigated. The results are presented in Appendix D of the *Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan* (CH2M HILL, April 3, 1998).

2.6.6 Fluoride Transport Migration in the Subsurface Matrix

The technical literature was reviewed for information bearing on the transport mechanisms for fluoride in soil and groundwater. The results of this assessment are presented in Appendix G of this document (Volume 3) and support the basis for the evaluation presented in Section 5.

Table 2-1
Groundwater Remedial Investigation Chronology
Reynolds Metals Company - Troutdale, Oregon

Date	Activity	Area Covered	Purpose	Description	Reference
1994	Preliminary Removal Site Assessment (Phase 1 - July)	RMC sitewide	• Assess shallow groundwater quality and flow directions.	• Install and sample 8 monitoring wells and measure water level elevations. • Sample 1 BPA well (substation location) and 1 surface water grab sample.	*Removal Site Assessment Report, Volume 1, Technical Report, and Volume 2, Technical Appendixes.* CH2M HILL, January 1995.
	Preliminary Removal Site Assessment (Phase 2 - August)	RMC sitewide and offsite (*Fairview Farms, Sundial Marine,* Gresham Sand & Gravel)	• *Assess shallow groundwater quality and flow directions*	• Install and sample 4 additional monitoring wells including west and northwest offsite locations. • Sample 5 RMC site production wells, 3 offsite wells, and 2 surface water grab samples. • Sample Bakehouse sumps and temporary wellpoints. • Water elevation measures of onsite and offsite monitoring wells, production wells, Bakehouse sumps.	*Removal Site Assessment Report, Volume 1, Technical Report, and Volume 2, Technical Appendixes.* CH2M HILL, January 1995.
	Groundwater Monitoring Program Initiated				
	November 1994 Groundwater Monitoring Event	Site perimeter	• Evaluate constituents nature and extent and assess groundwater flow characteristics. • Water levels measured monthly (manually) for all wells and electronically (using transducers) at selected wells.	• Sample 9 monitoring wells, 3 onsite production wells and 1 offsite well. • Measure water levels at each sampling location.	*Technical Memorandum No. GW-1: Quarterly Groundwater Monitoring Report No. 1.* CH2M HILL, January 9, 1995.
1995	PW-15 Decommissioning Early Action (January 1995)	Plant interior (Southeast side of Bakehouse)	• To prevent the potential for PW-15 to act as a conduit for downward vertical migration of groundwater near Scrap Yard area.	• Video survey conducted December 1994. • Groundwater sample collected in January 1995. • Well decommissioned between February 28 and March 24, 1995.	*Technical Memorandum No. 1: PW-15 Well Decommissioning Activities*. CH2M HILL, April 13, 1995.
	Shallow (Silt and Upper Gray Sand [UGS]) Monitoring Well Installations	Scrap yard, south landfill, north landfill, south wetlands areas	• Evaluate constituents nature and extent and assess groundwater flow characteristics within central site area. • Water levels measured monthly (manually) for all wells and electronically (using transducers) at selected wells.	• Install 18 monitoring wells and measure water level elevations.	*Technical Memorandum No. GW-7: Semiannual Groundwater Monitoring Report, December 1995 and February 1996.* CH2M HILL, August 1996.
	Supplemental Data Gathering at East Potliner Area (February 1995)	East Potliner	• Investigate potential migration from east potliner area to Sandy River	• Three sets of surface water samples collected and nine temporary well points installed, sampled, and later decommissioned. • Samples analyzed for cyanide, fluoride, PAHs, hardness, metals, SVOCs, PCBs.	*Technical Memorandum DS No. 3: East Potliner Area: Supplemental Data-Gathering Summary.* CH2M HILL, June 15, 1995.
	West Drainage Sampling Program (February 1995)	Salmon Creek	• Evaluate West Drainage discharge quality and quantity.	• One set of surface water and sediment samples were collected upstream and one set downstream of the confluence with the West Drainage. Surface water sample analyzed for cyanide, fluoride, PAHs, PCBs, PHCs, and metals.	*Technical Memorandum DS No. 1: West Drainage Area Sampling Program Data Summary.* CH2M HILL, May 10, 1995.
	Bakehouse Area Sump - Action Removal (Phased Approached between May 1995 and November 1997)	Bakehouse area	• Dewatering sumps sampled to assess presence of potential contaminants to provide clean-up and health and safety guidance pertaining to BH activities. • Temporary well points decommissioned because nonoperational and replaced by perforated dewatering sumps. • Sump cleaning and soil removal activities conducted prior to sump reconstructions-- to meet OWRD requirements for protection of groundwater. • Reconstruction and sump improvements for purpose of improved operations.	• 21 dewatering sumps sampled in and around the Bakehouse, along with the sump outfall location at the South Ditch (May 1995). • 57 dewatering temporary well points in and around the Bakehouse were decommissioned (June 1995). • Sumps were cleaned and soil removed. Each dewatering sump was reconstructed (Nov 1996 - January 1997). • ESP removal activities consisted of concrete, rock, and debris removal and replacement. Storm drain and auxiliary facilities reconstructed or improved. (June 1997 and November 1997). Also, Bakehouse Sump No. 1 decommissioned.	*Final Report: Bakehouse Sumps Area Removal Action.* CH2M HILL, April 27, 1998.
	South Wetlands Supplemental Data Gathering (September 1995)	South Wetlands	• Evaluate groundwater quality and determine horizontal and vertical gradients. • Assess water levels and provide supplemental groundwater sampling locations.	• Two temporary well points were installed and sampled. • *Four South Wetlands monitoring wells were sampled.* • Water levels measured.	*Technical Memorandum DS No. 8: South Wetlands Study Area Supplemental Data-Gathering Summary.* CH2M HILL, January 3, 1996. Results and Locations in: *Annual Groundwater Monitoring Report: August 1994 - August 1995.* CH2M HILL, February 1996.

Table 2-1
Groundwater Remedial Investigation Chronology
Reynolds Metals Company - Troutdale, Oregon

Date	Activity	Area Covered	Purpose	Description	Reference
	1995 Quarterly Groundwater Monitoring Program				
1995 Continued	February 1995 Groundwater Sampling Event	Sitewide	• Evaluate shallow constituents nature and extent and assess groundwater flow characteristics near site perimeter. • Water levels measured monthly (manually) for all wells and electronically (using transducers) at selected wells.	• 11 groundwater monitoring wells, 3 onsite production wells, and 1 offsite well sampled. • Water levels measured.	*Technical Memorandum No. GW-2: Quarterly Groundwater Monitoring Report No. 2*. CH2M HILL, April 13, 1995.
	May 1995 Groundwater Sampling Event	Sitewide	• Evaluate shallow constituents nature and extent and assess groundwater flow characteristics near site perimeter. • Water levels measured monthly (manually) for all wells and electronically (using transducers) at selected wells.	• Nine groundwater monitoring wells, 3 onsite production wells, and 3 offsite wells sampled. • Water levels measured.	*Technical Memorandum No. GW-3: Quarterly Groundwater Monitoring Report No. 3*. CH2M HILL, June 7, 1995.
	August 1995 Groundwater Sampling Event	Sitewide	• Evaluate shallow constituents nature and extent and assess groundwater flow characteristics near site perimeter and interior plant areas: scrap yard, south wetlands, south landfill, north landfill. • Water levels measured monthly (manually) for all wells and electronically (using transducers) at selected wells.	• Nine groundwater monitoring wells, 3 onsite production wells, and 1 offsite well sampled. • Water levels measured.	*Annual Groundwater Monitoring Report: August 1994 - August 1995*. CH2M HILL, February 1996.
	December 1995 Groundwater Sampling Event	Sitewide	• Evaluate shallow constituents nature and extent and assess groundwater flow characteristics near site perimeter and interior plant areas: scrap yard, south wetlands, south landfill, north landfill. • Water levels measured monthly (manually) for all wells and electronically (using transducers) at selected wells.	• 20 groundwater monitoring wells, 3 onsite production wells, and 3 offsite wells sampled. • Water levels measured.	*Technical Memorandum No. GW-7: Semiannual Groundwater Monitoring Report, December 1995 and February 1996*. CH2M HILL, August 1996.
1996	Columbia River and Sandy Rivers Supplemental Data Collection	Columbia River, Sandy River	• Evaluate groundwater discharge influence on surface water.	• Three surface water samples were collected: one along the east bank (upstream sample) and two along the west bank adjacent to refractory brick. Six sediment samples were collected adjacent to, upstream, and downstream of the refractory brick area. Four riparian soil samples were collected: three within and one upstream of the refractory brick.	*Technical Memorandum DS No. 13: Columbia and Sandy Rivers Supplemental Data Summary*. CH2M HILL, January 6, 1997.
	Early Action Production Well Decommissioning Activities (April - June 1996)	Central Plant site vicinity (Deep Groundwater Zone)	• Decommission production wells no longer in use. • Prevent the potential for downward vertical migration of constituents of concern in groundwater.	• Five deep production wells decommissioned (PW-04, PW-06, PW-11, PW-12, and PW-17).	Procedures outlined in *Memorandum WP. No. 38: Work Plan for Decommissioning Production Wells 9 and 14 at RMC - Troutdale*. CH2M HILL, May 18, 1998. Technical Memorandum Summary Report to be submitted.
	Phase 1 Intermediate and Deep Well Monitoring (February 1996)	Western and Northern RMC Site boundaries	• Assess potential groundwater impacts at site perimeter and determine movement patterns of shallow, intermediate, and deep groundwater. • Assess constituent movement from an improperly capped production well.	• Install 9 deep, 9 intermediate-depth, and 1 shallow well at different depths to sample lithographic change points. pH, conductivity, temperature and fluoride to be measured. • Install a variance monitoring well downgradient of Production Well 13, an improperly capped well at risk to allow downward vertical migration of contaminants.	*Memorandum WP No. 20: Draft Phase 1 Intermediate and Deep Zone Monitoring Well Installation Work Plan*. CH2M HILL, February 26, 1996.
	Phase 1A Groundwater Monitoring Well Installation (November and December 1996)	East potliner, south landfill, scrap yard areas, Northwest perimeter, and near surface water bodies	• Assess potential groundwater impacts at areas identified as east potliner, scrap yard, and south landfill; site perimeter and determine movement patterns of shallow, intermediate, and deep groundwater	• Install 13 shallow, 4 intermediate, and 3 deep wells.	*Memorandum WP No. 30: Phase 1A Well Installation Work Plan*. CH2M HILL, August 19, 1996.
	Production Well Groundwater Monitoring (April 1996)	RMC Central Plant site	• *EPA mandated groundwater monitoring as part of Production Well* PW09 decommissioning	• *Three production wells sampled. Conductivity, pH, temperature, fluoride,* cyanide, metals, PAHs measured.	*Memorandum GW No. 3: Groundwater Sample Collection at Production Wells PW11, PW12, and PW16*. CH2M HILL, May 28, 1996.
	South Wetland RI/FS (November 1996)	South wetlands	• Characterize groundwater quality (especially PCBs) downgradient of AOU-2 and north-central and southwestern areas of south wetlands.	• Four wells sampled for PCBs. • Five GW wells installed for use in quarterly monitoring (Mentioned above - Phase 1A Well Installations)	*Technical Memorandum DS No. 14: Data Summary for the South Wetlands Addendum to the RI/FS Work Plan, Part 1—Soil, Surface Water, and Groundwater Quality*. CH2M HILL, February 12, 1997.

Table 2-1
Groundwater Remedial Investigation Chronology
Reynolds Metals Company - Troutdale, Oregon

Date	Activity	Area Covered	Purpose	Description	Reference
	1996 Quarterly Groundwater Monitoring Program				
1996 Continued	February 1996 Groundwater Sampling Event	Sitewide	• Assess potential groundwater impacts at site perimeter and determine movement (groundwater flow direction and horizontal and vertical gradients) patterns of shallow, intermediate, and deep groundwater. • Evaluate groundwater quality at soil and debris areas and near surface water bodies. • *Water levels continue to be measured manually on a monthly basis for* all wells and electronically at selected wells.	• 23 groundwater monitoring wells, 3 onsite production wells, and 3 offsite wells sampled. • Water levels measured.	*Technical Memorandum No. GW-7: Semiannual Groundwater Monitoring Report, December 1995 and February 1996.* CH2M HILL, August 1996.
	May 1996 Groundwater Sampling Event	Sitewide		• 20 groundwater monitoring wells, 2 onsite production wells, and 1 offsite well sampled. • Water levels measured.	*Technical Memorandum No. GW-8: Semiannual Groundwater Monitoring Report, May 1996 and August 1996.* CH2M HILL, December 10, 1996.
	August 1996 Groundwater Sampling Event	Sitewide		• 40 groundwater monitoring wells, 2 onsite production wells, and 1 offsite well sampled. • Water levels measured.	
	November 1996 Groundwater Sampling Event	Sitewide		• 32 groundwater monitoring wells, 2 onsite production wells, and 1 offsite well sampled. • Water levels measured.	*Technical Memorandum No. GW-9: November 1996 Quarterly Groundwater Monitoring Results.* CH2M HILL, January 1997.
1997	Aquifer Slug Tests (January - March 1997)	RMC site	• Characterize aquifer hydraulic conductivity values to evaluate and modify constituent transport model.	• *Triplicate aquifer tests run on 35 deep, shallow, and intermediate-depth* monitoring wells. Pressure transducers in well casings measure air pressure and water table height changes as groundwater levels equilibrate after being forced into aquifer formation with compress gas.	*Technical Memorandum No. GW-16: Aquifer Test Results, RMC-Troutdale.* CH2M HILL, July 24, 1998.
	Short-Term Aquifer Tests (February - April 1997)	RMC sitewide	• Provide alternate data to evaluate anisotropic nature of aquifer system. • Compare with slug-test data to evaluate and modify contaminant transport model. • Evaluate Columbia River stage fluctuations on groundwater levels.	• Variation in response to groundwater pumping measured at 12 monitoring wells (6 deep, 3 intermediate, 3 shallow). Tests lasted 5-8 hours. Time-drawdown and recovery data used for analysis. Columbia River stage monitored continuously throughout test.	*Technical Memorandum No. GW-16: Aquifer Test Results, RMC-Troutdale.* CH2M HILL, July 24, 1998.
	South Ditch Groundwater / Surface Water Interactions - Piezometer Installations (May 1996)	South Ditch	• Provide shallow groundwater elevation data near both sides of South Ditch. • *Evaluate surface water / groundwater relationships to provide* information useful in interpreting site characterization data and in assessing remediation alternatives in the feasibility study.	• 16 piezometers installed along South Ditch (these piezometers were decommissioned during Summer 1998 after study was completed). • Subsurface geology logged. • Water levels measured.	*Technical Memorandum DS No. 18: Data Summary for the Wastewater Discharge Areas Addendum to the RI/FS Work Plan, Part 2.* CH2M HILL, June 1998.
	Sitewide Geoprobe Investigation and Groundwater Monitoring Well Installations (May - October 1997)	Sitewide and Bakehouse area	• Geoprobes (GPs) installed to evaluate groundwater fluoride concentration nature and extent across the site. • GPs installed to assess subsurface hydrogeologic sediment data. • Monitoring wells (MWs) installed to assess concentration and distribution of VOCs in groundwater near Bakehouse (BH). • MWs installed to evaluate potential for BH to act as PAH source to groundwater • Piezometers installed to evaluate extent of groundwater capture resulting from BH de-watering and to refine groundwater elevation data.	• 48 GPs installed with a resulting 399 samples collected. • Measure water levels during GP installation and document subsurface hydrogeology at selected boring locations. • 14 shallow MWs installed around Bakehouse. • *Six shallow piezometers installed around Bakehouse.* • Two UGS, 6 intermediate-depth, and 2 deep MWs installed at locations determined after assessing fluoride data results from sitewide Geoprobe investigation.	*Memorandum WP No. 36: Proposed 1997 Groundwater Work Plan.* CH2M HILL, June 1997. *Technical Memorandum No. GW-15: 1997 Groundwater Field Summary.* CH2M HILL, June 1998.
	Long-Term Aquifer Tests (September 1997)	Fairview Farms	• Provide alternate data to evaluate anisotropic nature of aquifer system. • Compare with slug-test data to evaluate and modify contaminant transport model. • Evaluate Columbia River stage fluctuations on groundwater levels.	• Groundwater drawdown levels measured using Geokon® dataloggers during approximate month-long pumping by Fairview Farms Well No. 4 and two nearby RMC production wells. Columbia River stage monitored continuously throughout test.	*Technical Memorandum No. GW-16: Aquifer Test Results, RMC-Troutdale.* CH2M HILL, July 24, 1998.

Table 2-1
Groundwater Remedial Investigation Chronology
Reynolds Metals Company - Troutdale, Oregon

Date	Activity	Area Covered	Purpose	Description	Reference
	1997 Quarterly Groundwater Monitoring Program				
1997 Continued	February 1997 Groundwater Sampling Event	Sitewide	Site characterization process continues: • Vertical variations in analyte concentrations evaluated by sampling all wells in selected groups. • *Water levels measured manually on monthly basis. Electronic water level* data collection continuing in conjunction with aquifer testing at the site. • February and August 1997 groundwater sampling events included "sweep," or sampling at each existing site well, for identified possible constituents of concern. *February and August selected to capture seasonal variations.*	• 69 groundwater monitoring wells, 2 onsite production wells, and 1 offsite well sampled. • Water levels measured.	*Technical Memorandum No. GW-10: February 1997 Quarterly Groundwater Monitoring Results.* CH2M HILL, June 1, 1997.
	May 1997 Groundwater Sampling Event	Sitewide		• 50 groundwater monitoring wells and 3 onsite production wells sampled. • Water levels measured.	*Technical Memorandum No. GW-11: May 1997 Quarterly Groundwater Monitoring Results.* CH2M HILL, July 31, 1997.
	August 1997 Groundwater Sampling Event	Sitewide		• 85 groundwater monitoring wells, 3 onsite production wells, and 1 offsite well sampled. • Water levels measured.	*Technical Memorandum No. GW-12: August 1997 Quarterly Groundwater Monitoring Results.* CH2M HILL, December 18, 1997.
	November 1997 Groundwater Sampling Event	Sitewide		• 70 groundwater monitoring wells sampled. • Water levels measured.	*Technical Memorandum No. GW-13: November 1997 Quarterly Groundwater Monitoring Results.* CH2M HILL, February 13, 1998.
1998	Continuation of Early Action Production Well Decommissioning Activities (Summer 1998)	Central Plant site vicinity (Deep Groundwater Zone)	• To prevent the potential for inactive production wells to act as a conduit for downward vertical migration of groundwater.	• PW-09 and PW-14 decommissioned during Summer 1998.	Procedures outlined in *Memorandum WP. No. 38: Work Plan for Decommissioning of Production Wells 9 and 14 at RMC - Troutdale.* CH2M HILL, May 18, 1998. Technical Memorandum Summary Report to be submitted.
	Source Area Data Needs - Geoprobe Investigation (Summer 1998)	East potliner, scrap yard, and south landfill soil and debris areas	• Additional data needs to be identified for east potliner, scrap yard, and south landfill areas. • Evaluate fluoride concentrations in soil and groundwater for purpose of refining nature and extent for both horizontal and vertical distribution of fluoride beneath these soil and debris areas.	• Install and sample from 20 Geoprobes/hollow-stem auger (HSA): 7 locations from south landfill (89 soil and 36 water samples), 5 locations from east potliner (52 soil samples and 30 water samples), and 8 locations from scrap yard (61 soil and 30 water samples). Field fluoride concentrations measured at 9 total locations for groundwater and 19 total locations for soil. • Measure water levels and catalog subsurface hydrogeology.	***See Appendix B in Volume 3 of this Groundwater RI Report.***
	1998 Groundwater Monitoring Program				
	February 1998 Groundwater Sampling Event	Sitewide	Extent of fluoride well defined. Shift monitoring focus from characterizing site constituents to monitoring plume configuration and concentration. Primary objectives: • Monitor changes in fluoride plume configuration with focus along plume perimeter. • Continue to monitor temporal changes in constituent concentrations at east potliner, scrap yard, and south landfill to assess effects of past remedial actions and provide baseline for potential new remedial actions. • Manual water level elevation monitoring frequency: Reduced from monthly to quarterly in March 1998. Electronic dataloggers no longer used to collect water level elevations.	• 55 groundwater monitoring wells sampled. • Water levels measured.	*Technical Memorandum No. GW-14: February 1998 Quarterly Groundwater Monitoring Results.* CH2M HILL, May 26, 1998.
	May 1998 Groundwater Sampling Event	Sitewide		• 17 groundwater monitoring wells sampled. • Water levels measured.	*Technical Memorandum No. GW-17: May 1998 Quarterly Groundwater Monitoring Results.* CH2M HILL, July 24, 1998.
	November 1998 Groundwater Sampling Event	Sitewide		• 55 groundwater monitoring wells sampled. • Water levels measured.	*Technical Memorandum No. GW-18: Groundwater Monitoring Results.* CH2M HILL, December 1998.

Table 2-2
Summary of Groundwater Monitoring Wells and Other Sampled Wells
Reynolds Metals Company - Troutdale, Oregon

Year	Well ID	Date Installed	Well Location (a)	Hydrogeologic Unit (b)	Total Depth (c)
Groundwater Monitoring Wells					
1994	MW01-019	7/12/94	Along South Ditch, South side of Bakehouse	Silt (S)	20
	MW08-027	7/7/94	Perimeter, northwest	Upper Gray Sand (UGS)	28
	MW05-025	7/8/94	Background, southeast	S	25
	MW06-024	7/8/94	Perimeter, Sundial Road	S	25
	MW03-017	7/9/94	Perimeter, Graham Road	S	18
	MW07-024	7/9/94	South of dike	S	25
	MW04-019	7/12/94	South wetlands, near Pump station	S	20
	MW09-030	8/4/94	North landfill	UGS	32
	MW12-021	8/4/94	Perimeter, Sundial Road	S	23
	MW10-023	8/5/94	South of dike	S	25
	MW11-017	8/5/94	East potliner	S	19
1995	MW14-015	7/11/95	Scrap yard	S	16
	MW13-022	7/12/95	Scrap yard	S	23
	MW24-010	7/12/95	Scrap yard	S	11
	MW25-024	7/12/95	Scrap yard	S	24
	MW15-024	7/13/95	Perimeter, Sundial Road	S	24
	MW16-014	7/13/95	South landfill	S	14
	MW18-016	7/20/95	South wetlands	S	16.5
	MW18-031	7/20/95	South wetlands	UGS	32
	MW17-016 (d)	7/21/95	South wetlands	S	17
	MW17-028	7/21/95	South wetlands	S	28.5
	MW19-013	7/21/95	South landfill	S	13.5
	MW25-035	7/24/95	Scrap yard	UGS	35.5
	MW26-012	7/24/95	South landfill	S	12.5
	MW02-012	7/25/95	Scrap yard	S	12.5
	MW20-026	9/1/95	North landfill	UGS	26.5
	MW23-025	9/1/95	North landfill	UGS	25
	MW21-012 (d)	9/5/95	North landfill	S	12
	MW21-025	9/5/95	North landfill	UGS	25
	MW22-027	9/6/95	North landfill	UGS	27
1996	MW02-034 (e)	1/18/96	Scrap yard	UGS	34
	MW06-176	5/3/96	Perimeter, Sundial Road	Deep (D)	178
	MW29-179	5/9/96	South of dike	D	182
	MW12-184	5/21/96	Perimeter, Sundial Road	D	184.5
	MW08-169	5/23/96	Perimeter, northwest	D	170.5
	MW15-175	6/4/96	Perimeter, Sundial Road	D	175.8
	MW03-175	6/17/96	Perimeter, Graham Road	D	175.5
	MW03-098	6/26/96	Perimeter, Graham Road	Intermediate (I)	100
	MW08-127	7/10/96	Perimeter, northwest	I	129
	MW10-165	7/31/96	South of dike	D	166
	MW21-176	8/14/96	North landfill	D	177
	MW27-176	8/26/96	Adjacent to Company Lake	D	176.5
	MW27-081	8/28/96	Adjacent to Company Lake	I	80.5
	MW10-090	9/12/96	South of dike	I	91
	MW29-090	9/18/96	South of dike	I	91
	MW06-094	9/20/96	South of dike	I	96
	MW15-086	9/23/96	Perimeter, Sundial Road	I	87

Table 2-2
Summary of Groundwater Monitoring Wells and Other Sampled Wells
Reynolds Metals Company - Troutdale, Oregon

Year	Well ID	Date Installed	Well Location (a)	Hydrogeologic Unit (b)	Total Depth (c)
1996 Continued	MW12-092	9/24/96	Perimeter, Sundial Road	I	92
	MW21-063	10/1/96	North landfill	I	65
	MW28-160	10/10/96	Bakehouse	D	161
	MW36-006 (d)	10/22/96	South wetlands	S	6.5
	MW37-012	10/23/96	South wetlands	S	12.5
	MW29-033	10/31/96	South of dike	UGS	33.5
	MW27-045	11/1/96	Adjacent to Company Lake	UGS	45
	MW38-007	11/1/96	Along Salmon Creek	S	7
	MW33-095	11/25/96	Scrap yard	I	95.5
	MW31-034	11/26/96	Fairview Farms	UGS	34
	MW32-165	12/2/96	Bakehouse	D	165
	MW38-035	12/2/96	Along Salmon Creek	UGS	36
	MW34-038	12/3/96	East potliner	UGS	38
	MW35-038	12/3/96	East potliner	UGS	38
	MW33-033	12/4/96	Scrap yard	UGS	33.5
	MW30-030	12/5/96	Near Gresham Sand & Gravel	UGS	30
	MW32-040	12/6/96	Bakehouse	UGS	41
	MW32-095	12/6/96	Bakehouse	I	95
	MW31-095	12/9/96	Fairview Farms	I	96
	MW37-030	12/9/96	South wetlands	UGS	30.5
	MW30-100	12/17/96	Perimeter, northwest, near Gresham Sand & Gravel	I	101
	MW33-165	12/30/96	Scrap yard	D	165.5
1997	MW40-018	6/11/97	Bakehouse	S	18.3
	MW40-030	6/11/97	Bakehouse	UGS	32
	MW42-013	6/11/97	Bakehouse	S	13.3
	MW42-027	6/11/97	Bakehouse	UGS	27.5
	MW41-033	6/12/97	Bakehouse	UGS	35
	MW44-011	6/12/97	Bakehouse	S	12
	MW44-027	6/12/97	Bakehouse	UGS	27.5
	MW41-020	6/13/97	Bakehouse	S	20.3
	MW43-015	6/13/97	Bakehouse	S	15.3
	MW43-027	6/13/97	Bakehouse	UGS	29
	MW45-042	6/16/97	Bakehouse	UGS	43
	MW46-018	6/16/97	Bakehouse	S	18.8
	MW46-043	6/16/97	Bakehouse	UGS	43.3
	MW45-017	6/17/97	Bakehouse	S	17.8
	MW39-095	6/26/97	Fairview Farms	I	95
	MW47-094	7/1/97	South landfill	I	95
	MW48-165	8/27/97	No. Side Casthouse	D	199
	MW48-055	9/2/97	No. Side Casthouse	I	56
	MW49-145	10/24/97	Scrap Yard	D	173
	MW49-095	10/29/97	Scrap Yard	I	95
	MW52-045	10/30/97	Adjacent to River, Near MW08	UGS	45
	MW50-094	10/31/97	So. Side Casthouse	I	95
	MW53-034	10/31/97	Adjacent to River, East of East Lake	UGS	35
	MW51-069	11/3/97	Adjacent to River, Near Gresham Sand and Gravel	I	69

Table 2-2
Summary of Groundwater Monitoring Wells and Other Sampled Wells
Reynolds Metals Company - Troutdale, Oregon

Year	Well ID	Date Installed	Well Location (a)	Hydrogeologic Unit (b)	Total Depth (c)
Piezometers					
1997	PZ17-019	10/29/97	Bakehouse	S	19.3
	PZ17-039	10/29/97	Bakehouse	UGS	40
	PZ18-023	10/31/97	Bakehouse	S	23.3
	PZ18-040	10/30/97	Bakehouse	UGS	42
	PZ19-014	10/31/97	Bakehouse	S	14.3
	PZ19-040	10/31/97	Bakehouse	UGS	40
RMC Site Production Wells					
1942 - 1970	PW03	6/42	North of Bakehouse	Deep	281
	PW07	1948	Northeast corner of Bakehouse	Deep	254
	PW08	1948	Northeast corner of Bakehouse	Deep	248
	PW10	1949	Between Casthouse and Bakehouse	Deep	625
	PW18	1970	Southeast corner of Bakehouse	Deep	300
Offsite Wells					
	Fairview Farms Well No. 4	1943 Well use: Irrigation	~ 1,300 feet west of Sundial Road	Deep	281
	Gresham Sand & Gravel	11/10/1967 Well Use: Domestic	Northwest of Sundial Road, adjacent to Columbia River	Deep	127
	Sundial Marine	12/19/1979 Well Use: Domestic	Northwest of Sundial Road, adjacent to Columbia River	Deep	233

Notes:
(a) Refer to Figure 2-1 for well locations.
(b) Silt = shallow well screened in silt.
UGS = shallow well screened in the upper gray sand.
I = intermediate-depth well screened in sand.
D = deep well screened in sand/gravel.
(c) feet below ground surface (ft bgs).
(d) Well abandoned in June 1998 (MW17-016, MW21-012, and MW36-006).
(e) MW24-024 was overdrilled and replaced with MW24-034 on January 18, 1996.

NA = information not available.

Table 2-3
History of Quarterly Groundwater Monitoring Program
Sample Frequency for Groundwater Monitoring Wells and Site Production Wells
Reynolds Metals Company - Troutdale, Oregon

Station	Installation Date	Jul-94	Aug-94	Sep-94	Nov-94	Feb-95	May-95	Aug-95	Sep-95	Oct-95	Dec-95	Feb-96	Apr-96	May-96	Jun-96	Jul-96	Aug-96	Sep-96	Oct-96	Nov-96	Dec-96	Jan-97	Feb-97	May-97	Jun-97	Aug-97	Nov-97	Feb-98	May-98	Aug-98
W01-019	07/12/94	X	X		X	X	X	X									X						X			X				
W02-012	07/25/95							X			X	X		X			X						X			X				
W02-024	**	X	X		X	X	X	X			X																			
W02-034	01/18/96											X		X			X						X			X				
W03-017	07/09/94	X			X	X	X	X									X			X			X	X		X	X	X		X
W03-098	06/26/96														X		X			X			X	X		X	X	X		X
W03-175	06/17/96														X		X			X			X	X		X	X			
W04-019	07/12/94	X	X		X	X	X	X									X						X			X				
W05-025	07/08/94	X															X			X			X	X		X	X	X		X
W06-024	07/08/94	X			X	X	X	X									X			X			X	X		X	X			
W06-094	09/20/96																	X		X			X	X		X	X			
W06-176	05/03/96												X				X			X	X		X	X		X	X			
W07-024	07/09/94	X				X											X						X	X		X	X			
W08-027	07/07/94	X	X		X	X	X	X				X					X			X			X	X		X	X			
W08-127	07/10/96																X			X			X	X		X	X			
W08-169	05/23/96													X			X			X		X	X	X		X	X			
W09-030	08/04/94		X		X	X	X	X				X					X						X			X		X		X
W10-023	08/05/94		X			X											X			X			X	X		X	X	X		X
W10-090	09/12/96																			X			X	X		X	X	X		X
W10-165	07/31/96													X			X			X			X	X		X	X	X		X
W11-017	08/05/94		X		X	X	X	X			X	X		X			X						X			X		X		X
W12-021	08/04/94		X		X	X	X	X									X			X			X	X		X	X	X		X
W12-092	09/24/96																	X		X			X	X		X	X	X		X
W12-184	05/21/96													X			X	X		X			X	X		X	X			
[illegible]-022	07/12/95							X			X	X		X			X						X			X		X		X
W14-015	07/11/95							X			X	X		X			X						X			X				
W15-024	07/13/95							X				X					X			X			X	X		X	X			
W15-086	09/23/96																	X		X			X	X		X	X	X		X
W15-175	06/04/96													X			X		X	X			X	X		X	X			
W16-014	07/13/95							X			X	X		X			X						X	X		X				
W17-016	07/21/95							X			X	X		X			X						X			X				
W17-028	07/21/95							X			X	X		X			X						X			X		X		X
W18-016	07/20/95							X			X	X		X			X						X			X				
W18-031	07/20/95							X			X	X		X			X						X			X				
W19-013	07/21/95							X			X	X		X			X						X			X				X
W20-026	09/01/95								X		X	X		X			X						X	X		X	X			
W21-012	09/05/95								X		X	X		X			X			X			X			X				
W21-025	09/05/95								X		X	X		X			X			X			X	X		X	X			
W21-063	10/01/96																	X		X			X	X		X	X			
W21-176	08/14/96													X						X			X	X		X	X			
W22-027	09/06/95								X		X	X		X			X						X	X		X	X	X		X
W23-025	09/01/95								X		X	X		X			X						X			X				
W24-010	07/12/95							X			X	X		X			X						X			X				
W25-024	07/12/95							X			X	X		X			X						X			X				
W25-035	07/24/95							X			X	X		X			X						X			X				
W26-012	07/24/95							X			X	X		X			X						X			X		X		X
W27-045	11/01/96																			X			X	X		X	X	X		X
W27-081	08/28/96												X							X			X	X		X	X	X		X
W27-176	08/26/96															X				X			X	X		X	X			
W28-160	10/10/96																		X	X			X	X		X	X			
W29-033	10/31/96																			X			X	X		X	X			
W29-090	09/18/96																			X			X	X		X	X	X		X
[illegible]-179	05/09/96												X				X			X			X	X		X	X	X		X
W30-030	12/05/96																						X	X		X	X	X		X
W30-100	12/17/96																				X		X	X		X	X	X		X

Table 2-3
History of Quarterly Groundwater Monitoring Program
Sample Frequency for Groundwater Monitoring Wells and Site Production Wells
Reynolds Metals Company - Troutdale, Oregon

Station	Installation Date	Jul-94	Aug-94	Sep-94	Nov-94	Feb-95	May-95	Aug-95	Sep-95	Oct-95	Dec-95	Feb-96	Apr-96	May-96	Jun-96	Jul-96	Aug-96	Sep-96	Oct-96	Nov-96	Dec-96	Jan-97	Feb-97	May-97	Jun-97	Aug-97	Nov-97	Feb-98	May-98	Aug-98
W31-034	11/26/96																						X	X		X	X	X		X
W31-095	12/09/96																			X			X	X		X	X	X		X
W32-040	12/06/96																						X	X		X	X	X		X
W32-095	12/06/96																				X		X	X		X	X	X		X
W32-165	12/02/96																			X			X	X		X	X			
W33-033	12/04/96																						X	X		X	X			
W33-095	11/25/96																			X			X	X		X	X	X		X
W33-165	12/30/96																		X				X	X		X	X	X		X
W34-038	12/03/96																						X	X		X	X	X		X
W35-038	12/03/96																						X	X		X	X	X		X
W36-006	10/22/96																				X		X	X		X	X			
W37-012	10/23/96																				X		X	X		X	X			
W37-030	12/09/96																				X		X	X		X	X			
W38-007	11/01/96																			X			X	X		X	X	X		X
W38-035	12/02/96																						X	X		X	X	X		X
W39-095	06/26/97																								X	X	X	X		X
W40-018	06/11/97																									X	X	X	X	X
W40-030	06/11/97																									X	X	X	X	X
W41-020	06/13/97																									X	X	X	X	X
W41-033	06/12/97																									X	X	X	X	X
W42-013	06/11/97																									Dry	Dry	Dry	Dry	Dry
W42-027	06/11/97																									X	X	X	X	X
W43-015	06/13/97																									Dry	Dry	X	X	Dry
W[illegible]-027	06/13/97																									X	X	X	X	X
W[illegible]-011	06/12/97																									Dry	Dry	Dry	Dry	Dry
W44-027	06/12/97																									X	X	X	X	X
W45-017	06/17/97																									X	X	X	X	X
W45-042	06/16/97																									X	X	X	X	X
W46-018	06/16/97																									X	X	X	X	X
W46-043	06/16/97																									X	X	X	X	X
W47-094	07/01/97																									X	X			
W48-055	09/02/97																										X	X		X
W48-165	08/27/97																										X	X		X
W49-095	10/29/97																										X	X		X
W49-145	10/24/97																										X	X		X
W50-094	10/31/97																										X	X		X
W51-069	11/03/97																										X	X	X	X
W52-045	10/30/97																										X	X	X	X
W53-034	10/31/97																										X	X	X	X
W03	06/01/42		X							X														X		X				
W07	1948		X							X																				
W08	1948		X		X	X	X	X		X	X	X																		
W10	1949		X		X	X	X	X		X	X	X		X			X			X			X	X		X				
W18	1970		X		X	X	X	X			X	X		X			X			X			X	X		X				

Notes:
** MW24-024 was overdrilled and replaced with MW24-034 on January 18, 1996.

Table 2-4

Historical Analyte List for Groundwater Monitoring Program Sampling Events (1994 - 1998)

Reynolds Metals Company - Troutdale, Oregon

Year	Month	*Number of Monitoring* Wells Sampled [a] / Number of Available Monitoring Wells	Number of Groundwater Wells Sampled by Analyte: Fluoride		CLP Metals [b] (Total)							General Chemistry	Cyanide		Chromium VI	VOCs	PAHs [b] (Total)	SVOCs	PCBs [b]
			Field (Orion selective-ion probe) [c]	Laboratory [d]	PP [e]	17 [f]	16 [g]	13 [h]	12 [i]	13 [j]	6 [k]	[l]	Total [m, n, o] 335.2M	Amenable 335.1/335.2	[p]	EPA 524.2/CLP	8270-SIM	(EPA 8270)	EPA 8080
1994	July/August	9 / 12	--	9	9	--	--	--	--	--	--	--	9 [N]	5	--	--	--	--	--
	November	9 / 12	--	9	9	--	--	--	--	--	--	--	9 [N]	4	--	--	--	--	--
1995	February	11 / 12	--	11	10	--	--	--	--	--	--	10	11 [N]	5	--	--	5	--	--
	May	9 / 12	--	9	9	--	--	--	--	--	--	--	9 [M]	2	--	--	--	--	--
	August	25 / 28 *(Numbers include 2 SWLS TWPs)*	--	25	--	16	--	9	--	--	--	16	25 [M]	--	25	10	5	10	10 (8080M)
	December	20 / 30	--	20	--	--	17	--	--	--	--	--	20 [M]	8	--	--	19	--	4 (8080M)
1996	February	23 / 31	--	23	--	--	23	--	--	--	--	--	23 [M]	7	--	5	9	--	--
	May	20 / 31	--	20	--	--	19	--	--	--	--	--	20 [M]	7	--	2	3	--	--
	August	40 / 40	--	40	--	--	40	--	--	--	--	9	40 [M]	15	--	14	30	--	5 (8080M)
	November	32 / 57	--	32	--	32	--	--	--	--	--	--	32 [M]	--	--	31	31		--
1997	February	69 / 69	69	69	--	48	--	--	--	21	--	69	69 [O]	6	--	69	69	--	1
	May	50 / 69	50	50	--	49	--	--	--	--	--	--	49 [O]	4	--	12	--	--	1
	August	85 / 85	85	30	--	67	--	--	--	18	--	23	85 [O]	6	--	56	31	--	--
	November	69 / 93	69	2	--	69	--	--	--	--	--	5	69 [O]	4	--	5	29	--	1
1998	February	55 / 93	55	4	--	--	--	--	--	--	28	--	--	--	--	8	--	--	--
	May	17 / 93	17	--	--	--	--	--	3	--	--	--	2 [N]	--	3	3	--	--	--
	August	55 / 90	55	4	--	--	--	--	3	--	25	--	2 [N]	--	3	6	--	--	--
Total:		598 / 93	400	357	37	281	99	9	6	39	53	132	474	73	31	221	231	10	22

Notes:

[a] Attempted total number of wells sampled. This number may include shallow wells that were "dry" and were not sampled.

[b] Total metals, PAHs, and PCBs. Field filtered dissolved samples for metals, PAHs, and PCBs are not reported.

[c] Field fluoride detection limit concentrations recorded as < 0.25 mg/L. After 1997, based upon new information from vendor, detection limit concentration recorded as < 0.40 mg/L.

[d] Laboratory fluoride analysis methods as follows: July 1994 - February 1995 = 340.2M, May 1995 - February 1996 = 340.1/340.2, and May 1996 - August 1998 = EPA 300.0.

[e] 13 metals, (PP = Priority Pollutant) including (both total and dissolved): antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. *Note:* 1994 sampling events did not include silver and thallium.

[f] 17 metals including: aluminium, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, thallium, vanadium, and zinc.
Note: August 1995 was 23 metals - includes CLP metals above plus Ca, Co, Mg, Mn, K, and Na.

[g] 16 metals including: aluminium, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, mercury, nickel, selenium, silver, thallium, and zinc.

[h] 13 metals including: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc.

[i] 12 metals including: aluminium, arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, and silver.

[j] 10 Metals = aluminium, arsenic, barium, beryllium, chromium, copper, iron, lead, nickel, and vanadium.

[k] 6 metals = aluminium, arsenic, beryllium, chromium, lead, and nickel.

[l] General Chemistry = Cations and Anions (Ca, Mg, Mn, Na, K, HCO_3, CO_3, SO_4, Cl, NO_3, Br), alkalinity, total dissolved solids, and hardness. <u>*Note*</u>: August and November 1997 also had boron and ammonia.

[m] Cyanide (Total, EPA Method 335.2 CLP-M) If total cyanide was detected, the samples were also analyzed for free (amenable to chlorination) cyanide (EPA Method 335.1/335.2M).

[n] *Cyanide (SW9010) If total cyanide was detected above the detection limit, the sample was analyzed for amenable cyanide.*

[o] Cyanide EPA Method 335.2M. If total cyanide was detected above the 0.2 mg/L MCL for amenable cyanide, the water sample was also analyzed for amenable cyanide.

[p] Total and Hexavalent chromium (SM-3500-CR): August 1995. Chromium VI (SW 7196): May and August 1998.

<u>**Abbreviations:**</u>

VOCs = volatile organic compounds.

PCBs = polychlorinated biphenyls. <u>*Note*</u>: During the four quarters in 1997 - only MW36-006 analyzed for PCBs.

PAHs = polynuclear aromatic hydrocarbons.

TPH = total petroleum hydrocarbons.

TWP = temporary well point in south wetlands area.

Table 2-5
Summary of Groundwater / Surface Water Activities
Reynolds Metals Company - Troutdale, Oregon

Date	Surface Water Body or Area	Purpose	Activity	Reference
1994-1997	Columbia River	Assess influence of Columbia River and Sandy River on RMC site groundwater.	• Hydraulic gradients assessed via monthly manual water elevation measurements	*Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan.* CH2M HILL, April 3, 1998.
July 1994	Columbia River	Evaluate potential migration of constituents via groundwater.	• Sediment samples and a surface water sample collected adjacent to the RMC outfall. Samples analyzed for cyanide, fluoride, metals, PAHs, PCBs, PHCs.	*Removal Site Assessment Report, Volume 1, Technical Report, and Volume 2, Technical Appendixes.* CH2M HILL, January 1995.
August 1994	Salmon Creek	Evaluate potential migration of constituents via groundwater.	• One surface water and three sediment samples collected downstream of the confluence with West Drainage. Surface water sample analyzed for cyanide, fluoride, PAHs, PCBs, PHCs, metals.	*Removal Site Assessment Report, Volume 1, Technical Report, and Volume 2, Technical Appendixes.* CH2M HILL, January 1995.
August 1994	East Lake	Assess groundwater discharge to East Lake.	• One midlake water sample collected and analyzed for cyanide, fluoride, PAHs, PCBs, PHCs, metals.	*Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan.* CH2M HILL, April 3, 1998.
February 1995	Sandy River	Investigate potential constituent migration from east potliner area to Sandy River via groundwater.	• Three sets of surface water samples collected and three temporary well points sampled. • Samples analyzed for cyanide, fluoride, PAHs, hardness, metals, SVOCs, PCBs.	*Technical Memorandum DS No. 3: East Potliner Area: Supplemental Data-Gathering Summary.* CH2M HILL, June 15, 1995.
February 1995	West Drainage, Salmon Creek	Evaluate West Drainage discharge quality and quantity for potential constituent migration via groundwater.	• One set of surface water and sediment samples was collected upstream and one set downstream of the confluence with the West Drainage. Surface water sample analyzed for cyanide, fluoride, PAHs, PCBs, PHCs, metals.	*Technical Memorandum DS No. 1: West Drainage Area Sampling Program Data Summary.* CH2M HILL, May 10, 1995.
Fall 1996	Columbia River, Sandy River	Assess whether groundwater discharging to rivers posed an unacceptable risk to ecological or human receptors.	• Three surface water samples were collected: one along the east bank (upstream sample) and two along the west bank adjacent to refractory brick. Six sediment samples were collected adjacent to, upstream, and downstream of the refractory brick area. Four riparian soil samples were collected: three within and one upstream of the refractory brick.	*Technical Memorandum DS No. 13: Columbia and Sandy Rivers Supplemental Data Summary.* CH2M HILL, January 6, 1997.
November 1996	South Wetlands	Characterize potential discharge into Salmon Creek from south wetlands and area groundwater.	• Surface flow measured using a calibrated wier, continuous flow recorder, staff gauge, stilling well. 4 samples collected during 3 storm events. DO, pH, tempreature, metals, PAHs, TOC, COD, PCBs, cyanide, fluoride measured.	*Technical Memorandum DS No. 14: Data Summary for the South Wetlands Addendum to the RI/FS Work Plan, Part 1—Soil, Surface Water, and Groundwater Quality.* CH2M HILL, February 12, 1997.
December 1996 to March 1997	Columbia River	Monitor effect of deposited dredge spoils on groundwater levels.	• Water level elevations at Gresham Sand & Gravel Monitoring Well 30 and Columbia River monitored before, during, and after dredging operation.	*Mamorandum GW No. 8: Water Level Elevation Data Summary for Response to Dredging at Gresham Sand and Gravel.* CH2M HILL, July 31, 1997.
1997	Columbia River, Sandy River	Assess influence of Columbia River and Sandy River on RMC site groundwater.	• Hydraulic gradients assessed via data loggers and pressure transducers from RMC monitoring wells and Columbia River.	*Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan.* CH2M HILL, April 3, 1998.
May 1997	Salmon Creek	Assess potential discharge from groundwater to Salmon Creek and assess constituent flux.	• Water elevations in nearby monitoring wells and in Salmon Creek measured to determine flow direction. Estimates based on Darcy flux groundwater flow calulations also made. • 1994-1997 groundwater sample data reviewed to assess constituent concentration flux trends.	*Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan.* CH2M HILL, April 3, 1998.
May - September 1997	South Ditch	Evaluate groundwater/surface water interactions in wastewater discharge areas.	• Weekly surface water and groundwater elevation data collected from 8 staff gauges, 26 Monitoring Wells, and 16 piezometers, encompassing wet and dry periods.	*Technical Memorandum DS No. 18: Data Summary for the Wastewater Discharge Areas Addendum to the RI/FS Work Plan, Part 2.* CH2M HILL, June 17, 1998.
August - November 1997	Columbia River, Sandy River	Monitor discharge of fluoride from groundwater to surface water.	• Twenty-two Geoprobes and 3 monitoring wells installed adjacent to rivers and sampled. (Installed as part of the 1997 sitewide Geoprobe investigation.)	*Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan.* CH2M HILL, April 3, 1998.
September 1997	Company Lake	Assess groundwater quality upgradient and downgradient of Company Lake.	• Water samples collected and analyzed from 11 Geoprobes (5 upgradient, 6 downgradient). Analyzed for cyanide, fluoride, metals, PAHs, pH, temperature, conductivity, vertical redox potential structure.	*Technical Memorandum DS No. 18: Data Summary for the Wastewater Discharge Areas Addendum to the RI/FS Work Plan, Part 2.* CH2M HILL, June 17, 1998.
November 1997	East Lake, Sandy River	Assess groundwater discharge to Sandy River.	• Two Geoprobes installed near East Lake and a monitoring well installed to southeast to determine groundwater influence on Sandy River. (Geoprobes installed as part of the 1997 sitewide Geoprobe investigation.)	*Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan.* CH2M HILL, April 3, 1998.
November - December 1997	Columbia River	Determine effect of Columbia River stage on groundwater elevations.	• Columbia River stage data collected and nearby RMC east/west monitoring well array monitored hourly via dataloggers and pressure transducers. • Vertical hydraulic gradients assessed via use of shallow, intermediate, and deep depth monitoring wells.	*Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan.* CH2M HILL, April 3, 1998.
January 1998	East Lake	Assess groundwater discharge to East Lake.	• Two surface samples, one from east end, one from west end of East Lake. Samples analyzed for cyanide, fluoride, PAHs, PCBs, PHCs, metals.	*Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan.* CH2M HILL, April 3, 1998.
April 1998	South Ditch	Assess the presence of potential discharge of groundwater on water quality in South Ditch.	• Twenty-one dewatering sumps sampled in and around BH, along with the sump outfall location at the South Ditch.	*Final Report: Bakehouse Sumps Area Removal Action.* CH2M HILL, April 27, 1998.

SECTION 3

Conceptual Hydrogeologic Model

SECTION 3

Conceptual Hydrogeologic Model

This section provides a conceptual understanding of the regional and site hydrogeology at the Reynolds Metals Company facility and surrounding areas. The following information on the conceptual hydrogeologic model is addressed:

- Section 3.1: Regional and local geology, including identification and description of regional and site hydrogeologic units
- Section 3.2: Groundwater hydrology, including groundwater elevations and flow directions, and aquifer hydraulic properties
- Section 3.3: Surface water interactions with groundwater
- Section 3.4: Local groundwater use survey

3.1 Regional and Local Geology

A literature review was conducted to develop an understanding of geography, climate, geology, and hydrology for the study area. Reports used in this review are listed in Table 3-1 and include documents prepared by the U.S. Geological Survey (USGS), the Oregon Department of Environmental Quality (ODEQ), the Oregon Water Resources Department (OWRD), and technical consultants.

3.1.1 Regional Hydrogeologic Units and Structure

The RMC facility is located on the eastern part of a structural basin called the Portland Basin. Previous studies of this area (summarized in Table 3-1) generally agree on the character and extent of the aquifer units, although the stratigraphic terminology used often differs, as illustrated in Figure 3-1. The units described in this section of the report generally follow the more recent informal hydrogeologic-unit names adopted by Swanson et al. (1993). One exception to the nomenclature of Swanson et al. is the inclusion of the Blue Lake Aquifer (BLA), which is an important producing aquifer for the eastern part of the City of Portland's Columbia South Shore Wellfield. This aquifer, described by Hartford and McFarland (1989), correlates with the lower portions of the Unconsolidated Sedimentary Aquifer (USA) described by Swanson et al., and is included in this report because of its proximity to the RMC facility.

3.1.1.1 Regional Hydrogeologic Units

Table 3-2 summarizes the regional hydrogeologic units present in the RMC site vicinity, and Figure 3-2 shows a generalized regional stratigraphic column (Swanson et al., 1993). The geologic units of the Portland Basin, from youngest to oldest, generally include:

- Recent Alluvium
- Flood Deposits

- Troutdale Formation
- Interfingered Sandy River Mudstone and Troutdale Formation
- Columbia River Basalt Group and Older Rocks

The sedimentary units (alluvium downward through interfingered Sandy River Mudstone and Troutdale Formation) were formed by a variety of geologic processes and events that affected the character and course of the ancestral and present-day Columbia River drainage system. These units include cataclysmic, glacially-derived flood deposits of gravel, sand, and silt; volcanic mudflows of sand, silt, ash, gravel, and other volcanic debris deposited from nearby eruptive centers; and fine-grained sediments deposited in a closed-basin lacustrine environment.

The recent alluvium and flood deposits collectively make up the Unconsolidated Sedimentary Aquifer and the Blue Lake Aquifer. These shallow Quaternary-age deposits are characterized by alluvial and fluviolacustrine sediments, primarily confined to the areas near current and former locations of the Columbia River and other major tributaries (Swanson et al., 1993). The USA and BLA aquifers are stratigraphically similar in position but differ in grain size and, therefore, transmissivity. As shown in the regional stratigraphic column (Figure 3-2), the Troutdale Gravel Aquifer (TGA) forms the base of the Quaternary deposits, except where it has been eroded (such as beneath the RMC facility). The TGA is primarily composed of coarser grained Pleistocene-age Troutdale Formation sediments.

The geologic units or deposits that generally lie beneath the younger sedimentary deposits include the Sandy River Mudstone and the Troutdale Formation (see Figure 3-2). These Pliocene-age units tend to be more consolidated than the overlying Quaternary sedimentary deposits. Interfingered Sandy River Mudstone and Troutdale Formation contain, from youngest to oldest, Confining Unit 1 (CU1), Troutdale Sandstone Aquifer (TSA), Confining Unit 2 (CU2), and the Sand and Gravel Aquifer (SGA).

The Older Rocks unit defined by Swanson et al. (1993) is of pre-Pliocene age and is exposed in the southern and eastern portion of the Portland Basin. The Older Rocks unit includes the Scappoose Formation and rocks of the Skamania Volcanic Series (Swanson et al., 1993). Extrusive igneous basalt flows of the Columbia River Basalt Group (CRBG) are believed to overlie the older rock deposits in the Portland area. However, the depth, thickness, and extent of the basalt flows are not well defined. Groundwater may be encountered in basalt interflow zones within the CRBG and/or within marine sedimentary rocks. Wells screened in proximity to marine sedimentary rocks may encounter saline groundwater.

3.1.1.2 Regional Hydrogeologic Structure

Figure 3-3 shows a surface map of the hydrogeologic units present near the RMC facility. This figure also shows the locations of subsurface geologic cross sections A-A′ and B-B′, which are presented in Figures 3-4 and 3-5, respectively. The map and sections have been prepared from reviews of geologic logs for production wells and monitoring wells completed in the area. In addition, the preparation of these sections has incorporated interpretations contained in reports by Swanson et al. (1993), Bet and Rosner (1993), and Roger N. Smith Associates, Inc. (1997).[1]

The surface geologic map shows the following structural features:

- The RMC facility is situated on top of the USA. In areas west and southwest of the site, the Troutdale Formation (consisting of the TSA and the TGA) is exposed at the ground surface in many locations. These exposures comprise a dome that is the structural high point of a large regional fold. Information from borehole geophysical logs and other well logs indicates that the northeast portion of the structural dome was cut by the east-west trending fault shown in Figure 3-3 (Bet and Rosner, 1993).
- Along the northeast flank of this structural dome, the Troutdale Formation is absent. This is likely the result of erosion that occurred during large-scale flooding events associated with outbursts from Pleistocene-age glacial Lake Missoula. The flooding removed the Troutdale Formation after it was uplifted, creating a trough along the fault plane that was subsequently filled with the coarse paleo-channel sediments that constitute the BLA (Bet and Rosner, 1993).

The west-east trending cross section A-A′ (Figure 3-4) shows the following:

- The unconsolidated materials that form the USA beneath the RMC facility were deposited into a deep trough by the Columbia and Sandy Rivers. This is indicated by the following observations:
  - Confining units CU1 and CU2, and the regional water-bearing units (including the TGA and TSA), are not present beneath the USA in the RMC site vicinity. Their absence is thought to be due to erosion by the ancestral Columbia River.
  - The well logs for the deepest RMC production wells (PW10 and PW14) indicate the presence of relatively uniform sands within the USA, with the upper portion of the underlying SGA consisting of a mixture of sands with occasional silt and gravel layers having variable colors and degrees of lithification. Deeper portions of the SGA contain mixtures of sand, gravel, and cemented gravel. The heterogeneity and depth of the deep SGA materials suggests that they are deposits from both the Columbia and Sandy River systems that were dropped into a deep trough. The upper SGA, which has a greater sequence of sands, may also consist of bed-load deposits from both river systems. In contrast, the USA deposits are delta deposits associated with the Sandy River bed load, which consists of gray sands.
- The well log from the deepest RMC production well (PW10) indicates a hard shale zone at about 550 feet below ground surface (bgs). It is probable that the shale referenced on the driller's log is a thin, platy basalt sequence rather than an actual shale unit, and it therefore likely represents the top of the Older Rocks sequence defined by Swanson et al. (1993).

[1] Large-scale regional cross sections of the Portland Basin are not presented in this report because several of the aquifer units within the basin are not present in the vicinity of the RMC site. Refer to Plates 1 and 2 in Swanson et al. (1993) for regional cross sections of the Portland Basin.

- Between the BLA and the RMC facility, the geologic contact between the SGA and the overlying USA is based on the geologic logs for Portland Water Bureau (PWB) monitoring wells BLA-3 and PWB-5 (RNSA, 1997) and RMC production wells PW10 and PW17. The top of the SGA is defined at wells PW10 and PW17 by a contact between sands and underlying fine-grained materials (defined as silt, sandy silt, clay, and hard-packed sand in the drillers' logs). At monitoring well PWB-5, the top of the SGA is defined by the contact between relatively unconsolidated sands and silts and underlying semiconsolidated deposits of gravel and sandstone.
- The BLA's eastern edge lies approximately 1 ¼ mile west of Sundial Road, which forms the western property boundary of the RMC facility. The eastern extent of the BLA is defined by the recent installation of PWB monitoring wells BLA-3 and PWB-5 (RNSA, 1997) and from inspection of geologic logs for City of Portland (COP) wells No. 13, No. 17, and No. 18. These data indicate that the upper portion of the BLA is bounded to the east by confining unit CU2.
- The upper USA water-bearing zone overlies, and is likely in hydraulic communication with, the BLA. The BLA and SGA are thought to be separated by CU2 based on the drillers' logs for City of Portland production wells and monitoring wells. The material beneath the BLA at COP Well No. 13 is interpreted to be CU2, rather than the SGA, based on the geologic log's description of blue clay directly beneath the BLA at a depth of 173 feet bgs. In addition, the remaining drilled depth encountered blue clay and other materials as described in the geologic log. However, the CU2 may be absent beneath a limited portion of the BLA according to other published geologic cross sections (RNSA, 1997). Consequently, portions of the BLA may be in hydraulic connection with the SGA.

The northwest-southeast trending cross section (B-B′ in Figure 3-5) depicts the following:

- The USA is present as a 200-foot-deep sedimentary channel beneath the RMC facility. The USA thins dramatically beginning approximately one-half mile southeast of the site. In this area, the USA is underlain by the TSA and CU2, which both lie above the SGA. Farther south, near the City of Troutdale, the geologic log for City Well No. 4 shows the thicker sequences of both the TSA and the CU2. City Well No. 4 taps groundwater from the SGA at depths between 493 and 563 feet bgs.
- The deepest materials encountered beneath the RMC facility site are the basalt flows and consolidated volcanic rock debris associated with the Older Rocks unit. The unit crops out in the Columbia River to the north-northwest of the RMC site. Exposures are observed at Ione Reef (located at about river mile 120 in the Columbia River) and at the eastern border of Lady Island.
- The top of the Older Rocks unit dips sharply to the south and is present at a depth exceeding 750 feet south of the RMC facility, based on the geologic log for the Troutdale Airport well. The log for this well, which was drilled using air rotary methods, indicates that the materials consist of interbedded layers of blue sands, blue clay, and "broken rock" from a depth of about 261 feet to the well's total depth (750 feet). This description makes it difficult to interpret whether these materials are associated with the SGA or with the Older Rocks. However, the log does indicate that the static water level in the well (which is screened over a depth interval of 435 feet to 750 feet) was recorded as

20 feet bgs after completion of the well. This depth is equivalent to an elevation of about 10 feet, which is similar to the average stage in the Columbia River.

In addition, the specific capacity of the well was recorded as 14 gallons per minute per foot (gpm/ft), which is similar to the specific capacities indicated on the drillers' logs for the two deepest RMC production wells (PW10 and PW14, which have specific capacities of 23 gpm/ft and 10 gpm/ft, respectively). Furthermore, the Troutdale Airport well is screened at a similar depth interval as PW10 and PW14, which have screened intervals of 440 feet to 558 feet bgs and 608 feet to 637 feet bgs, respectively. Consequently, these data suggest that the Troutdale Airport well is completed in the SGA and does not extend into the Older Rocks. This interpretation is also consistent with regional interpretations indicating that the Older Rocks lie at an elevation of about 800 feet below mean sea level. (See Plate 3 in Swanson et. al, 1993.)

3.1.2 Local Hydrogeologic Units

Figure 3-6 shows the locations of two geologic cross sections that were constructed at a site scale. Figures 3-7 and 3-8 present the two sections (C-C′ and D-D′). Section C-C′ illustrates the site geology parallel to the regional groundwater flow direction (from southeast to northwest). Section D-D′ illustrates the site geology perpendicular to the regional flow direction. Both cross sections were aligned to take advantage of the locations of deep water supply wells (the RMC production wells and the Troutdale Airport and City of Troutdale wells) and to provide representative views of the site geology. Key observations from the site-scale sections are as follows:

1. A sequence of well-sorted sands approximately 400 feet thick is present from RMC production well PW18 south towards the Troutdale Airport well. (See Section C-C′.) At the Troutdale Airport well, the well-sorted sand is absent below a depth of about 260 feet, where interbedded silty and gravelly clays are present.

2. North of PW18, the thick sequence of well-sorted sand contains a distinct 20-foot to 60-foot thick layer of silt and sandy silt that is present at a depth of approximately 175 feet bgs. (See Section C-C′.) RMC production wells PW10, PW14, PW18, and other production wells not shown on this section (PW05 and PW16) were all constructed with screened intervals immediately above this silt/sandy silt layer. The silt/sandy silt layer thickens to the north, but is present only as far north as the Bonneville Power Administration (BPA) well. The layer is absent at monitoring well MW29 and north of the dike.

3. The sands that are present beneath the silt/sandy silt layer are present only as far north as PW10 and perhaps monitoring well MW32. North of this area, gravel is present rather than sand. This gravel unit thins considerably in a northward direction due to a sharp rise in the elevation of the top of the Older Rocks unit.

4. The east-west cross section through the RMC wellfield (Section D-D′) shows that the silt/sandy silt layer is absent in the eastern portion of the section and is discontinuous farther west.

   - In the eastern portion of the section, sands are present in most of the vertical profile, with a 20-foot to 40-foot layer of cemented gravel separating the upper 100 feet of sand from the deeper sands. In this area, RMC production well PW08 contains multiple screen intervals, including in the gravel layer. Nearby well PW07 is at the eastern edge of the silt/sandy silt layer and appears to be screened across this layer. Nearby well PW05 is screened both above and below the silt/sandy silt layer.

- In the middle of the section, the silt/sandy silt layer thickens and is underlain by sands east of PW03 and gravels and cemented gravels at and west of PW03. The geologic log for PW01 indicates that the silt/sandy silt layer is absent at this location. The logs for the nearest wells to the west (PW16) and the east (BPA) suggest that the layer is present at those locations.

5. Both cross sections show the presence of surficial sands and silts across the site. Recent drilling activities have resulted in subdivision of these shallow surficial materials into a surficial sand unit and an underlying silt unit in much of the south plant area, where scrap yard, south landfill, east potliner, and south wetlands are located. The surficial sand unit is typically less than 10 feet thick and is above the water table during the summer in some locations. The silt unit is below the water table year-round and has a typical thickness of 20 feet in the south plant area, except at scrap yard where it is as little as 8 feet thick. North of the Corps of Engineers (COE) flood control dike, the silt is much thinner and is above the water table except during extremely wet seasons.

3.2 Groundwater Hydrology

An understanding of groundwater hydrology is important for assessing the fate and transport of chemical constituents that are present in site soils and groundwater. The site groundwater hydrology has been described in several previous documents, including quarterly groundwater monitoring reports for the period 1996 through 1998 and the *Preliminary Conceptual Hydrogeologic Model Report, Volumes 1 and 2* (CH2M HILL, March 21, 1996). The following subsections summarize groundwater flow patterns and hydraulic properties of the waterbearing formations situated beneath the RMC facility.

3.2.1 Groundwater Elevations and Flow Directions

Data collected at the RMC facility since 1994 indicate that site groundwater flow is strongly controlled by hydraulic connections with the Columbia and Sandy Rivers, as well as by pumping from RMC production wells. The rivers exert a strong control on groundwater elevations in the upper gray sand (UGS), intermediate zone, and deep zone, with the Columbia River exerting a stronger influence than the Sandy River. The RMC production wells exert strong influences in much of the deep zone and more localized influences on portions of the UGS and the intermediate zones. Site surface water features (particularly Company Lake) also control local groundwater flow patterns. Precipitation infiltration directly controls groundwater elevations only in the silt unit.

Because of the large number of controls on the system and the complexity of the dynamics governing their influence on the aquifer (particularly in the case of the rivers), the groundwater flow system is highly three-dimensional in nature. In addition, groundwater flow patterns in localized areas can vary dramatically over relatively short periods of time due to variations in RMC production well pumping and river stages. River stage fluctuations occur daily, due to tidal influences, and seasonally, due to variations in flow as managed by the series of dams on the Columbia River upstream of the site. The subsections below discuss general horizontal flow patterns (as interpreted from groundwater elevation contour maps) and vertical flow patterns (as interpreted from hydrographs at monitoring well clusters).

3.2.1.1 Horizontal Flow

Figures 3-9, 3-10, 3-11, and 3-12 show groundwater elevation contour maps for the silt unit, the UGS, the intermediate zone, and the deep zone on August 4, 1998. These maps show groundwater elevations during a period of relatively dry summertime conditions and moderate to seasonal low stages in the Columbia and Sandy Rivers. The maps show a generally southeast-to-northwest flow direction in each of the four units, with groundwater flowing towards both rivers. The Columbia River is a regional discharge location for groundwater in the UGS, the intermediate zone, and the deep zone. The Sandy River is a discharge point for groundwater in the UGS and may also capture groundwater from portions of the intermediate zone under certain conditions. Silt unit groundwater generally moves vertically into the UGS or horizontally over limited distances towards surface depressions (such as South Ditch and south wetlands).

The groundwater elevation contour maps show the following additional prominent features in this flow pattern:

- A cone of depression exists in the deep sand zone around production wells PW07 and PW08. (See Figure 3-12.) The cone of depression also extends upwards into the intermediate zone (Figure 3-11), but the drawdowns are substantially less than in the deep zone (as indicated by the differences in the contours shown in the two figures). The cone of depression is associated with pumping at these two wells, which were pumping at a combined rate of approximately 1,575 gpm (2.3 mgd) at the time of the August 1998 water level measurements. The wells are discharge points for groundwater.
- A groundwater divide extends from the southeastern corner of the facility northwards towards Company Lake in the UGS, the intermediate zone, and the deep zone. The divide is formed by the following:
  - **The combined effects of the cone of depression in the deep zone and geologic controls that prevent the cone of depression from extending west of this localized area.** The specific geologic control that maintains water levels in the area west of the cone of depression is the sequence consisting of a silt/sandy silt layer underlain by cemented gravel. (See Figure 3-8.) The water level data at wells MW27, MW29, MW32, and MW48 indicate that groundwater in these areas experiences little drawdown in response to pumping from production wells PW07 and PW08.
  - **Leakage from Company Lake.** Recharge from Company Lake is also a contributor to the formation of the hydraulic divide, primarily north of the dike. Interactions between Company Lake and groundwater are discussed in Section 3.3.2 of this report.
- Near the bakehouse, a cone of depression is present in the silt unit. This cone of depression is thought to be present because of the pumping action from the dewatering sumps surrounding the bakehouse. In the UGS, the groundwater elevation contours indicate that a hydraulic mound is present in the UGS. The presence of the mound could

be the result of differences in the thickness of the silt unit and the UGS in this area, as well as to the shallower depths of the UGS wells compared with UGS wells in other portions of the site.

The groundwater elevation contour maps for August 1998 are generally representative of conditions that have been measured during other seasons since water level monitoring began in 1994. An exception is during periods of high runoff in the Columbia River, when the river stage can become sufficiently high to cause reversals of groundwater flow directions close to the river and, in some cases, across the site. A sitewide groundwater reversal was observed in the UGS, the intermediate zone, and the deep zone during May 1997 when the river stage was at an elevation of 22 feet NGVD (*Technical Memorandum No. GW-11: May 1997 Quarterly Groundwater Monitoring Results*, CH2M HILL, July 31, 1997). Reversals of groundwater flow directions were also observed north of the flood control dike during May 1998 (*Technical Memorandum No. GW-17: May 1998 Groundwater Monitoring Results*, CH2M HILL, July 24, 1998).

Because of the infrequent nature and relatively short duration of the gradient reversals, the net movement of groundwater is towards the Columbia and Sandy Rivers. It is unlikely that the brief gradient reversals result in a significant volume of surface water entering the aquifer from the rivers.

3.2.1.2 Vertical Flow

The understanding of vertical flow patterns at the site has been obtained from the quarterly water level monitoring events and from the Fairview Farms aquifer test, which used continuous-recording devices to monitor water levels at nested well clusters throughout the site.[2] As described previously in quarterly monitoring reports and in the *Preliminary Conceptual Hydrogeologic Model Report, Volumes 1 and 2*, vertical gradients tend to be small, except for downward gradients between the silt unit and the underlying UGS and downward gradients in deeper zones near production wells PW07 and PW08.

Figures 3-13 through 3-15 show hydrographs of groundwater elevations at three of the well clusters that were monitored during the Fairview Farms aquifer test. The hydrographs also show the pumping cycles and the differences in groundwater elevations between the wells completed in the intermediate and deep sand zones.[3] Each hydrograph also shows the hourly data-logger records for the Columbia River stage, as well as the 24-hour moving average of the river stage. The hydrographs show that the vertical gradients were predominantly downwards throughout the aquifer system during each phase of the test. The gradients were particularly strong at MW21 (Figure 3-14) and at wells close to the production wells. (See the groundwater elevation contour maps in Figures 3-11 and 3-12.) Small upward gradients were observed at various times in upgradient well MW03. Other notable observations from the Fairview Farms test were:

[2] The Fairview Farms aquifer test was conducted from September 4 through September 30, 1997. The test consisted of pumping RMC production wells PW03 and PW07 and Fairview Farms well FF04. Details of the test procedures and the results obtained from the test are presented in the document titled *Technical Memorandum No. GW-16: Aquifer Test Results, RMC-Troutdale* (CH2M HILL, July 23, 1998).

[3] Groundwater elevation data that were collected manually are shown with a symbol, while data logger records are shown without symbols. [See also the legend of each figure for indications of whether the data were collected manually (designated as "Hand" in the legend) or using data loggers (designated as "DL" in the legend).] The hydrograph legends also indicate the unit in which the well was completed (UGS, intermediate sand, and deep sand).

- **Geologic controls on the magnitude of the vertical gradient.** At MW21, the deep zone well is completed in a deep sequence of thick sand and shows relatively low groundwater elevations because it is in close hydraulic connection with the river. In contrast, the UGS and intermediate zone wells show much higher water levels because they are constructed in a shallow sand zone that overlies a layer of cemented gravel separating the intermediate zone from the deep zone. The large vertical gradient is the result of the high groundwater levels in this shallow sand zone (resulting from perching of water on top of the gravel) and the combined influences of the river and pumping on the deep well. At MW27, which is a similar distance from the river, the deep zone is comprised of the gravel and cemented gravel layer, with no underlying sequence of thick sands. Consequently, the deep zone well has groundwater levels that are similar to those in the UGS and the intermediate zone.[4] Therefore, the vertical gradient is much smaller at MW27 than at MW21.
- **The areal extent of the influence of the river stage on groundwater levels.** This is shown by upgradient well MW03 (Figure 3-13), which indicates responses to river stage changes that lag the trends in river stage by only a few hours.
- **The instantaneous nature of the response to pumping in each well.** This response is particularly strong at the beginning of the test (on September 4, 1997). Prior to the test, groundwater elevations were declining throughout the area. The data indicate that this decline continued during the first 5 days of the test (through September 9) in response to a decline in the river stage during this period. The slope of the groundwater level decline prior to the test is similar to the rate of decline during the first few days of the test. The instantaneous response to pumping is shown in Figures 3-13 through 3-15 as a suddenly greater rate of decline that began when wells PW03 and PW07 were turned on and that lasted for about half of a day.

3.2.2 Aquifer Hydraulic Properties

The principal hydraulic properties of the aquifer system that govern groundwater flow rates and chemical fate and transport processes are the horizontal and vertical hydraulic conductivities. The horizontal hydraulic conductivities of the silt unit, the UGS, and the intermediate and deep sand zones have been estimated using data collected from the sitewide aquifer testing program that was conducted from January through September 1997 (*Technical Memorandum No. GW-16: Aquifer Test Results, RMC-Troutdale*, CH2M HILL, July 23, 1998). This aquifer testing program consisted of slug tests at 35 monitoring wells; short-term (5- to 8-hour) low-flow pumping tests at 12 monitoring wells; and an aquifer test involving controlled pumping from two RMC production wells (PW03 and PW07) and a former irrigation well on the Fairview Farms property.

3.2.2.1 Horizontal Hydraulic Conductivity

Tables 3-3, 3-4, 3-5, and 3-6 provide statistical summaries of measured hydraulic conductivity values for the silt unit, the UGS, the intermediate zone, and the deep zone, respec-

[4] The higher water levels in the deep well at MW27 compared with MW21 do not appear to be the result of recharge from Company Lake, as the groundwater elevations in the UGS and the intermediate zone are similar at both well locations. See the groundwater elevation contour maps for the UGS and the intermediate zones (Figures 3-10 and 3-11, respectively).

tively. Based on the tabulated results, typical values of the horizontal hydraulic conductivity are estimated to be:

- Silt unit: 1 to 2 ft/day (3.5×10^{-4} cm/sec to 7×10^{-4} cm /sec)
- UGS: 35 ft/day (1×10^{-2} cm/sec) along and north of the flood control dike, 2 ft/day (7×10^{-4} cm /sec) on the plant site
- Intermediate sand: 100 to 120 ft/day (3.5×10^{-2} cm /sec to 4.0×10^{-2} cm /sec) according to short-term testing data, but 150 to 160 ft/day (5×10^{-2} cm /sec) according to slug test data
- Deep sand: Variable according to location and type of test performed. Excluding the short-term test data, which produce unreasonably low values, the distribution of horizontal hydraulic conductivities is as follows:
  - Eastern portion of the site: 100 to 120 ft/day (3.5×10^{-2} cm /sec to 4.0×10^{-2} cm /sec)
  - Site interior: 130 to 175 ft/day (4.5×10^{-2} cm /sec to 6.0×10^{-2} cm /sec)
  - Fairview Farms and western portion of the site: 75 ft/day (2.5×10^{-2} cm/sec) according to slug test data, 150 ft/day (5×10^{-2} cm /sec) according to long-term test data

These values were estimated by fitting water level data from each test to commonly used analytical solution methods (which are identified in the tables). Because these equations are analytical in nature, they assume the existence of simpler hydrologic conditions than are commonly found in the field. Consequently, the hydraulic conductivity estimates may be over or under actual hydraulic conductivity values.

3.2.2.2 Vertical Hydraulic Conductivity

The vertical hydraulic conductivity of the silt unit was measured during 1998 in four soil samples collected from the three soil and debris areas located in the south plant area (scrap yard, east potliner, and south landfill). Table 3-7 summarizes the vertical hydraulic conductivity data, as well as other physical parameters that were measured in these samples. For the silt unit, the vertical permeability ranged from between 0.0003 and 0.0006 ft/day (approximately 10^{-7} cm/sec) beneath south landfill and east potliner and 0.006 ft/day (approximately 2×10^{-6} cm/sec) beneath scrap yard. Based on these results and the horizontal hydraulic conductivity values for the silt unit (1 to 2 ft/day), the ratio of horizontal to vertical hydraulic conductivity (the Kh:Kv ratio) is estimated to be between 100:1 and 1,000:1 for the lowest-permeability soils and on the order of 100:1 for the somewhat more permeable silts situated beneath scrap yard.

Vertical hydraulic conductivities were not directly measured in the underlying sand units. The upper gray sand unit contains variable amounts of fine-grained materials and likely has a Kh:Kv ratio of 100:1 or less. Because the intermediate and deep sand units generally contain very low amounts of fine-grained materials, the Kh:Kv ratio may be on the order of 20:1 or less in these zones.

3.3 Surface Water Interactions with Groundwater

The principal surface water features are the Columbia and Sandy Rivers, Company Lake, East Lake, South Ditch, south wetlands, West Drainage, and Salmon Creek. The onsite surface water features are shown in Figure 3-16.

3.3.1 South Plant Surface Water Features

The principal surface water features in the south plant area are South Ditch, south wetlands, West Drainage, and Salmon Creek. The hydrologic relationships of these features to site groundwater are discussed below and in Appendix A of Volume 3.

3.3.1.1 South Ditch

South Ditch is the primary drainage feature in the portion of the RMC facility south of the flood control dike. As shown in Figure 3-16, South Ditch is divided into an eastern reach and a western reach. The eastern reach is dry during the summer months and collects surface water runoff and groundwater seepage from areas near the dike and north of the east potliner soil and debris area during the winter months. West South Ditch extends from East South Ditch to a pump station located at the western end of the ditch (near the southwest corner of the building housing the potlines). West South Ditch conveys the seasonal flow from East South Ditch, effluent from the sanitary wastewater treatment plant and the process wastewater treatment plant, and groundwater discharged from a system of shallow dewatering wells at the bakehouse. These combined flows are pumped from West South Ditch through an underground pipe into Company Lake as part of the NPDES-permitted treatment process. Water levels in the ditch are controlled by the pumping station, which is designed to prevent water from rising above an elevation of approximately 15 feet.

East South Ditch is a gaining ditch during the winter months when groundwater elevations are at their seasonal high levels. The ditch then becomes a losing ditch for a brief period (approximately 2 to 4 weeks during a typical year) once groundwater levels decline below the ditch bed. During this period, the East South Ditch provides recharge to groundwater until it goes dry. In contrast, the West South Ditch is wet year-round. It is a gaining ditch during the winter months and becomes a losing ditch (recharging the underlying groundwater) beginning in June or July during a typical year. Detailed discussions of groundwater/surface water interactions at South Ditch are contained in Attachment A of the document titled *Technical Memorandum DS No. 18: Data Summary for the Wastewater Discharge Areas Addendum to the RI/FS Work Plan, Part 2* (CH2M HILL, June 17, 1998).

3.3.1.2 South Wetlands

South wetlands is a seasonal surface water feature. It receives water almost solely from direct precipitation during the rainy season. The water level gradually declines beginning in the spring due to a combination of direct evaporation, plant transpiration, and leakage to underlying groundwater. Leakage to underlying groundwater is believed to be limited, as groundwater elevation contour maps for the silt unit do not indicate the presence of a hydraulic mound beneath the area.[5] This is consistent with observations that the bed of

[5] See Figure 3-9 and other silt unit groundwater elevation contour maps for previous time periods (contained in quarterly monitoring reports for the RMC facility).

south wetlands is composed of fine-grained materials. These materials allow the wetland to accumulate and retain water throughout the rainy season, which would not occur if the soils allowed for rapid infiltration into underlying groundwater.

3.3.1.3 Salmon Creek

Salmon Creek flows along a portion of the southwest border of the RMC property. The creek conveys stormwater from urban and industrial areas and also collects stormwater from portions of the RMC property. Survey data indicate that the creek has a bed elevation of between 12.6 and 13.1 feet along the reach that lies just west of south wetlands. This elevation is lower than groundwater elevations that have been historically measured in nearby silt unit monitoring wells (particularly MW12, MW18, and MW38). In addition, it has been observed that the creek contains water year-round, but contains mostly standing water (with little or no active flow) during the summer months. These observations and the water level data together indicate that the creek is gaining during the summer months, receiving groundwater discharge from the silt unit.

3.3.2 Company Lake

The principal surface water feature north of the dike is Company Lake, the wastewater treatment pond which covers an area of approximately 14 acres. The pond is part of the facility's NPDES-permitted stormwater and wastewater treatment system and is a naturally occurring surface water feature that was present before the RMC facility was constructed. The water level in the pond is maintained at a relatively steady elevation by a Parshall flume that is located along an outfall ditch that flows to the Columbia River. The flume has an elevation of 15.5 feet mean sea level (MSL). During occasional periods of high water in the Columbia River (stages above approximately 20 feet MSL), water flows into Company Lake from the river via the outfall ditch. Staff gage readings during 1997 indicate that the water level in the pond ranged from 15.37 feet to 16.18 feet (*Technical Memorandum DS No. 18: Data Summary for the Wastewater Discharge Areas Addendum to the RI/FS Work Plan, Part 2*).

Figure 3-17 shows a schematic cross section aligned in an east-west direction through the center of the pond. The cross section shows the following:

- The elevation of the bed of Company Lake ranges from about sea level in the eastern half of the lake to 10 feet or higher in the western half of the pond. The bed of the pond consists of native sand and silt materials overlain by a layer of process residue. A field investigation program at Company Lake concluded that the thickness of the process residue ranged from nonexistent to more than 4 feet (*Technical Memorandum DS-15: Company Lake Supplemental Data Summary*, CH2M HILL, March 26, 1997).
- Shallow groundwater levels can be higher or lower than the water level in the pond. As discussed in Section 3.2, shallow groundwater levels in this area are controlled by the stage of the Columbia River.

Descriptions of the permeability of the bed of the pond and of groundwater/surface water interactions are presented below.

3.3.2.1 Bed Permeability and Leakage Rates

Permeability testing of three core samples of the native sediments indicates that the vertical hydraulic conductivity of the native sediment in Company Lake is low. The core samples yielded sediment permeabilities ranging from 1.2 x 10^{-6} cm/sec to 1.9 x 10^{-6} cm/sec (*Technical Memorandum DS No. 17: Data Summary for the Wastewater Discharge Areas Addendum to the RI/FS, Part 1*, CH2M HILL, December 12, 1997). These permeabilities are equivalent to 0.0034 to 0.0054 feet/day.

A water balance calculation was performed for Company Lake for the period August 23 through October 20, 1997. This time period included the Fairview Farms aquifer test and covered a period when groundwater levels were consistently below the lake level. The water balance calculation concluded that groundwater was being recharged by the pond at a rate of between approximately 280,000 and 430,000 gallons per day (gpd). It is likely that a portion of this flow was through the bed of the lake, with some flow also occurring through the pond's sidewalls, which consist of both native and non-native materials.

3.3.2.1 Company Lake Interactions with Groundwater

Figure 3-18 displays hydrographs that compare the Company Lake stage (the elevation of the Parshall flume) with shallow groundwater elevations in nearby monitoring wells. The hydrographs show surface water recharging groundwater for a period of about 16 months (June 1994 through September 1995). Drought conditions existed during this period, causing groundwater levels and the Columbia River stage to be consistently lower than the water level in the pond.

Beginning in October 1995, normal to above-normal precipitation and river flow patterns occurred in the region. This caused seasonality in the relationships between groundwater elevations and the water level in the pond. From December 1995 through May 1996, groundwater levels and river stages oscillated greatly and were higher than the water level in the pond for distinct periods of time (causing groundwater to discharge into the pond). However, there were also distinct periods during these months when the water level in the pond was higher than the groundwater elevations and the river stage. During the summer and fall months, groundwater elevations and river stages were consistently lower than the water level in the pond, causing groundwater to be recharged by the pond.

Other indications of the significance of Company Lake to groundwater recharge are the following:

- **Groundwater quality data and leachate tests of cores containing sediments and process residue.** The highest fluoride concentrations measured in Geoprobes downgradient of the pond during 1997 ranged from 15.9 to 24.5 mg/L, which is comparable to concentrations of 18.2 to 23.2 mg/L that were measured in the leachate tests (*Technical Memorandum DS No. 18: Data Summary for the Wastewater Discharge Areas Addendum to the RI/FS Work Plan, Part 2*).

- **Geochemical analyses of groundwater, pond water, and leachate from core samples of the pond's bed.** Figure 3-19 is a Piper trilinear diagram that compares the chemistry of these waters. The diagram shows upgradient groundwater samples (south of the pond) in gray, downgradient groundwater samples (north of the pond) in blue, pond water samples in green, and leachate samples in red. The diagram shows that each of the four sample types plot in four relatively distinct groups. The diagram also shows that the group of downgradient samples falls between the group of upgradient samples and the group of leachate samples. This indicates that the pond has altered the geochemistry of the groundwater, and that the pond is a source of water to the underlying groundwater system. This interpretation, together with the similarity of fluoride concentrations in leachate and downgradient groundwater, indicates that Company Lake has historically been a long-term source of fluoride to groundwater in the area north of the flood control dike.

3.3.3 Other Surface Water Features North of the Dike

3.3.3.1 Former West Company Lake

Figure 3-16 shows the outline of the former West Company Lake. West Company Lake was once part of Company Lake but was filled and is now owned by Gresham Sand & Gravel (GS&G). Dredged materials from the Columbia River have been stockpiled over West Company Lake as part of GS&G operations since 1968. By 1971, the west end of the pond had been filled with dredge spoils. Borings in West Company Lake indicate that the existing fill material is between 8 and 24 feet thick.

3.3.3.2 East Lake

East Lake lies approximately 600 feet to the east of Company Lake. East Lake is a naturally occurring surface water feature. Aerial photographs from the 1930s show that East Lake lies within an abandoned former channel of the Sandy River that once connected East Lake to the river and to Company Lake. Today, East Lake is a shallow depression that contains water only during a portion of the year. During periods of unusually high flows and stages in the Sandy River, water from the Sandy River can flow into East Lake; otherwise, there are no inlets or outlets. Water levels in East Lake are thought to represent Columbia and Sandy River stage elevations and may also represent local groundwater elevations when the regional water table is at its seasonal high elevation.

3.3.4 Columbia and Sandy Rivers

As discussed in Section 3.2.1, the Columbia and Sandy Rivers exert a strong control on groundwater elevations at the RMC facility. The following subsections discuss the effects of this control on groundwater discharge patterns and the relative rate of groundwater discharge compared with river flow rates.

3.3.4.1 Impact of Interactions on Groundwater Discharge Rates

Groundwater elevations vary over short periods of time due to tidal effects on the river stage. Variations also occur on a monthly and seasonal basis as a result of variations in flows released from the dams located on the Columbia River upstream of the RMC facility. Although these factors cause occasional reversals in the predominantly southeast-to-northwest groundwater flow direction across the site, these reversals are relatively short-lived. A detailed analysis of river stages and groundwater elevations at monitoring well clusters across the site demonstrated that these occasional reversals do not exist for sufficient durations to have a significant impact on groundwater flow directions and long-term groundwater discharge rates to the Columbia and Sandy Rivers. (See Appendix C of the *Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan*, CH2M HILL, April 3, 1998.*)*

3.3.4.2 Mixing Factors for Groundwater Discharging to Rivers

Calculations have been performed to estimate mixing factors comparing the rates of groundwater discharge to seasonal low surface water flows in the Columbia and Sandy Rivers.[6] This work is described in detail in Appendix D of the *Draft Surface Water and Sediment Areas Addendum to the RI/FS Work Plan*. The calculations consisted of the following steps:

1. Identifying the size of the mixing cell into which groundwater discharges in the river. The size of the cell is based on (1) the cross-sectional area of the portion of the river into which groundwater discharges and (2) the length of the river shoreline adjacent to the RMC property.
2. Calculating the river flow rate through the mixing cell. The river flow rate through the cell is the total river flow rate multiplied by the percentage of the river's cross-sectional area that is occupied by the mixing cell.
3. Calculating the groundwater flow rate into the mixing cell. The groundwater flow rate is the Darcy flow rate, which equals the product of the hydraulic conductivity, the hydraulic gradient, and the thickness of the portion of the aquifer containing fluoride. (See Section 4 for discussions of the presence of fluoride in groundwater.)
4. Calculating the hydraulic mixing factor for groundwater discharging into surface water. If the ambient concentration in the river (Cr) is assigned a value of zero to represent non-detects, then the mixing factor (MF) is defined from:

$$MF = (Qg + Qr) / Qg = 1 + (Qr / Qg)$$

where Qg is the groundwater flow rate and Qr is the river flow rate.

The principal parameters that required specification for this analysis were:

- River flow rates
- Percent of the total river flow within the mixing cell
- Hydraulic conductivity
- Hydraulic gradient
- Thickness of aquifer zone

Mixing factors were developed for three different sets of flow rates in both rivers. These were:

- 7Q10 flow, which is the 7-day sustained low flow that would be expected to occur once every 10 years
- Monthly low flow, which is the average flow during the month of lowest flow

[6] The mixing factor is an expression of the mixing of waters that arises when groundwater (migrating at relatively slow rates of flow) discharges into surface water (which migrates at high velocities and flow rates). The mixing factor is defined mathematically as the ratio of the sum of groundwater and surface water flow rates to the groundwater flow rate.

- Mean annual flow

The river flow rates were based on stream gauge records for the Columbia River at The Dalles, Oregon and for the Sandy River below the Bull Run River. For the Columbia River, mixing factors were calculated for mixing cells containing 20 percent, 40 percent, and 50 percent of the river flow. For the Columbia River, this selection was based on a schematic geologic and bathymetric cross section north of the dike (Figure 3-20). For the Sandy River, general principals of groundwater flow associated with rivers (such as the Sandy River) that partially penetrate an aquifer suggest that no more than 50 percent of the riverbed is likely to receive discharge from the aquifer and that the portion could be substantially lower. Consequently, mixing factors were calculated for mixing cells containing 10 percent, 25 percent, and 50 percent of the Sandy River flows.

The aquifer thickness in the vicinity of the Columbia River was set equal to 30 feet, based on the distribution of fluoride shown in Figure 3-20. The same value was assumed for the Sandy River mixing factor calculations. Hydraulic gradients were estimated from water level elevation contour maps for February 1997 for the UGS. The selected hydraulic conductivity value (190 feet/day) was the highest value obtained for the UGS from slug tests conducted on monitoring wells located north of the flood control dike.

Tables 3-8 and 3-9 summarize the mixing factors for the Columbia and Sandy Rivers, respectively. The mixing factors range between 34,000 and 188,000 for the Columbia River and between 90 and 4,400 for the Sandy River. These mixing factors are conservative for two reasons: (1) because the maximum hydraulic conductivity was used, and (2) because the river flow rates used in the analysis underestimate actual 7Q10, monthly low, and mean annual flows by not accounting for flows from tributaries located below the gauging stations.

3.4 Local Groundwater Use Survey

A survey of local groundwater use was performed to identify current groundwater use close to the Reynolds Metals Company facility. The survey consisted of querying an Oregon Water Resources Department database containing well log reports for water supply wells, and an additional OWRD database containing groundwater rights information. The following subsections discuss the results of the database searches for well logs (Section 3.4.1) and groundwater rights (Section 3.4.2).

3.4.1 Well Log Search

An inventory of water wells located within a one-mile radius of the site (to the south and west) was conducted by querying the online OWRD well log database, as well as by reviewing published and unpublished data. The well log search was conducted for production wells located within East Multnomah County in Township 1 North (T1N), Range 3 East (R3E), Sections 14, 22, 23, 24, 25, 26, and 27. Areas north of the Columbia River and east of the Sandy River were excluded from the search because these surface water features are local and regional discharge points for the shallow (and possibly deep) flow systems. Therefore, wells located north or east of the rivers are not likely to be potential receptors of constituents in shallow groundwater beneath the RMC facility.

Table 3-10 presents an inventory of water supply wells for which water well reports are on file at OWRD. Approximate well locations are shown in Figure 3-21, and available water well driller reports are presented in Appendix D. For convenience, the tabulated water well reports are identified by well inventory numbers (WIN) in Table 3-10. The original well owner, well location information, and current well use as identified on the driller's log have been field verified for some of the local wells surrounding the site. Locations for several wells were not identified because of poor location-specific documentation on the water well report forms. These wells are identified in Figure 3-21 and Table 3-10. Also, with the exception of WIN 5, the inventory does not include wells that have been abandoned.

A total of 38 water well reports were obtained for this area. As shown in Table 3-10, county assessor records indicate that one well reported to be in the search area (WIN 10) is actually located in Township 1 South (T1S), which is outside of the search area. For the remaining 37 wells, the water well reports show the following reported uses of groundwater:

- 17 domestic wells
- 7 wells with domestic and other uses (such as irrigation or manufacturing)
- 5 municipal wells (one of which has been temporarily abandoned)
- 3 irrigation wells (one of which was for a dairy)
- 4 industrial wells (one of which has been temporarily abandoned)
- 1 test well

In addition to the reported 37 water wells in the area, 18 production wells have been installed historically at the RMC site. (See Figure 3-22 for their locations and status.) In addition to industrial use, groundwater from these wells provides drinking water to RMC employees.

Total well depths for the 37 offsite wells within the search area ranged from 23 feet (WIN 29) to 1,060 feet (WIN 31), and reported groundwater yields ranged from 12 to 1,500 gpm. The majority of wells within the 1-mile radius are screened or perforated within materials described as water-bearing sand and gravel. These sediments most likely correspond to the Unconsolidated Sedimentary Aquifer described in Section 3.1.

An exception is a 750-foot-deep, Port of Portland public-supply well (WIN 8) that is located approximately 300 feet south of the RMC facility, at the Troutdale Airport. (See Figures 3-6 and 3-21 for the location of this well.) This well is cased to 738 feet bgs and screened in the Sand and Gravel Aquifer over a depth interval of 435 to 738 ft bgs. The pumping test yield, reported on the OWRD water well report, was 800 gpm with 58 feet of drawdown over the 24-hour pumping period. Troutdale Airport personnel indicate that the airport is currently connected to the City of Troutdale water distribution system and that the well is inactive and may have been abandoned, although no abandonment log was on file at OWRD (Young, 1995). Young also reported that water from this well was of poor quality, or "bad tasting." Another well that is screened within deeper sediments is RMC production well PW10. Groundwater from this well, screened within deeper SGA sediments, is reported to contain slightly elevated concentrations of chloride that may be associated with deeper marine sedimentary rocks.

Other significant observations from the well log survey are as follows:

- Two wells (WIN 5 and 6) are located at the BPA Troutdale Substation adjacent to the north side of the plant. BPA staff indicate that the WIN 5 well is not used because of historically low yield conditions. Because of elevated hydrogen sulfide concentrations, groundwater from the WIN 6 well is not used for potable water; bottled water is supplied for the seven or eight substation employees (Purchase, July 1995). The yield at WIN 6 is estimated at about 300 gallons per day (Sherer, 1995).
- Two other wells are potentially located downgradient and northwest of the RMC facility: an industrial well at Sundial Marine Tug and Barge (WIN 1) and a domestic well (currently not used for potable water) at Gresham Sand & Gravel (WIN 2).
- High-yield municipal wells owned by the City of Troutdale (WIN 12), City of Fairview (WIN 31, WIN 32, and WIN 33), and Wood Village (WIN 38) are located upgradient, southeast of the RMC site and cross-gradient, southwest of the RMC site (Figure 3-21).

3.4.2 Groundwater Rights Inventory

Groundwater use permits were requested for T1N, R3E, Sections 14, 15, 22, 23, and 24.[7] A total of three groundwater use permits were identified for the site area. The data for these three permits are presented in Table 3-11. RMC owns two of these permitted wells (WIN 3 and WIN 7), which are both located on the Fairview Farms property. The other permit owner is the Bonneville Power Administration, as identified from the well log search (WIN 5 in Table 3-10). Additional queries of the OWRD database for surface water permit data showed no point of diversions from the Columbia and Sandy Rivers in this same search area.

3.5 Summary of Conceptual Hydrogeologic Model

The hydrogeology at the Reynolds Metals Company facility and surrounding areas can be summarized as follows:

1. The facility is located in the eastern part of the Portland structural basin. The facility is underlain by two regional aquifer systems (the Unconsolidated Sedimentary Aquifer and the deeper Sand and Gravel Aquifer). These aquifers contain sands and gravels deposited by the ancestral Columbia and Sandy Rivers. These unconsolidated sediments are underlain by consolidated materials associated with the Older Rock Unit, which lies at depths ranging from near ground surface in the Columbia River to 550 feet beneath the RMC facility and 800 feet or greater south of the facility.
2. The site-specific hydrostratigraphy is as follows:
    - A surficial unit called the silt unit is present south of the Corps of Engineers flood control dike. In this area, the silt unit consists of a surficial sand horizon and an underlying silt horizon. The surficial underlying sand is typically less than 10 feet

[7] Groundwater permit data are also available for sections 25 through 28 but are not presented here because these locations are considered to be upgradient of the RMC facility.

thick. The silt horizon is typically 20 feet thick, except at scrap yard where it is as little as 8 feet thick.

- The silt unit is underlain by well-sorted sands. These sands are subdivided into the upper gray sand, the intermediate sand zone, and the deep sand zone. These sands are present to depths of 400 feet in the southern portion of the site and approximately 175 feet or less in the remainder of the site.
- The materials underlying the well-sorted sands consist of interbedded sand and gravel layers with occasional silt and sandy silt layers. In places, the well-sorted sands are separated from the interbedded materials by a distinct layer of silt or sandy silt.

3. Groundwater flow patterns within the silt unit are controlled primarily by precipitation infiltration and the influences of localized surface water features (specifically South Ditch, south wetlands, and Salmon Creek, which are localized discharge points for groundwater). Silt unit groundwater generally moves vertically into the UGS or horizontally over limited distances toward these surface water features.
4. The ambient groundwater flow direction in the UGS and deeper zones beneath the RMC facility is generally from the south and southeast to the north and northwest, with groundwater discharging to the Columbia and Sandy Rivers. However, groundwater flow patterns are also strongly controlled by pumping from the RMC production wells and (in localized areas) by surface water features (particularly the Columbia River, the Sandy River, and Company Lake). Specific observations follow:

- A distinct cone of depression is observed in the eastern part of the site during pumping from the RMC production wells. However, this cone of depression only extends a limited distance to the west where low-permeability materials (silt, sandy silt, and cemented gravel) are present.
- Pumping of the RMC production wells can induce strongly downward gradients throughout the site at high pumping rates. During the 26-day Fairview Farms aquifer test, the vertical gradient between the intermediate and deep zones was downwards throughout most of the test at most well locations.
- Groundwater elevations respond quickly to changes in pumping rates and to changes in the stages of the Columbia and Sandy Rivers. Although the rivers influence groundwater levels throughout the site, they are regional groundwater discharge points (particularly the Columbia River). Along the portion of the river shorelines that adjoin RMC property, the mixing factor describing groundwater discharge rates into the river are estimated to range from 34,000 to 180,000 for the Columbia River and from 90 to 4,400 for the Sandy River.
- In the vicinity of the Company Lake wastewater treatment pond, strong downward vertical flow occurs because of leakage from the pond into underlying groundwater. This is suggested by differences in water levels and geochemistry between the pond and the underlying groundwater system, and by the fluoride distribution in groundwater, which is discussed in detail in Section 4 of this report.

5. The horizontal hydraulic conductivities of the hydrogeologic units beneath the RMC facility are estimated to be:
   - Silt unit: 1 to 2 ft/day
   - UGS: 2 to 35 ft/day
   - Intermediate sand: 100 to 150 ft/day or higher
   - Deep sand: 75 to 175 ft/day
6. Well construction records and water rights records on file at the Oregon Water Resources Department indicate that offsite uses of groundwater occur in areas within one mile of the plant. For this search area, records were found for 37 wells, in addition to the RMC production wells. These wells withdraw groundwater from the USA and (in areas south of the USA's southern boundary) from other aquifer zones. Additional queries of the OWRD database for surface water permit data showed no points of diversion from the Columbia and Sandy Rivers in this same search area.

Table 3-1
Summary of Literature Reviewed
Reynolds Metals Company - Troutdale, Oregon

Author	Date	Investigation Area	Title (Agency, Document Number)
Trimble, D.E.	1963	Portland	*Geology of the Portland, Oregon and Adjacent Areas* (U.S.G.S. Bulletin 1119, p. 119)
Mundorff, M.J.	1964	Clark County	*Geology and Ground-water Conditions of Clark County, Washington, with a Major Alluvial Aquifer along the Columbia River.* (U.S.G.S. WSP 1600, p. 268)
Hogenson, G.M. and B. L. Foxworthy	1965	East Portland	*Groundwater in the East Portland Area.* (U.S.G.S. WSP 1793, p. 78)
Willis, R.F.	1977	Portland Well Field	Groundwater Exploratory Program (Bureau of Water Works, Portland, Oregon, p. 284)
Willis, R.F.	1978	Portland Well Field	*Pilot Well Study.* (Bureau of Water Works, Portland, Oregon, p. 150)
Hoffstetter, W.H.	1984	Portland Well Field	*Geology of the Portland Well Field.* (Oregon Geology, Oregon DOGAMI, v. 46, no. 6, p. 63- 67)
Noble, J.B. and C.Ellis	1980	Vancouver	*City of Vancouver Groundwater Source and Use Study --Vol. I, Summary.* (Report Prepared for the City of Vancouver by: Robinson, Noble, and Carr, Inc., Tacoma, WA, p. 42)
Carr, J.R. and Associates	1985	South Clark County	*Groundwater Management and Development Plan.* (Report Prepared for Clark Co. Public Utility District by: J.R. Carr and Associates, Gig Harbor, WA.)
Hartford, S.V. and W.D. McFarland	1989	Portland Well Field	*Lithology, Thickness, and Extent of Hydrogeologic Units Underlying the East Portland Area, Oregon.* (U.S.G.S. WRI Report 88-4110, p. 23)
Parametrix	1991	East Multnomah Co.	*East Multnomah County Database and Model, Geologic Interpretation--Detailed Study Area.* (Prepared for Oregon DEQ)
James N. Bet and Malia L. Rosner (Landau Associates)	1993	East Multnomah Co.	*Geology near Blue Lake County Park, Eastern Multnomah County, Oregon.* (Oregon Geology, Vol. 55)
Swanson, R.D., W.D. McFarland, J.B. Gonthier, and J.M. Wilkinson	1993	Portland Basin	*A Description of Hydrogeologic Units in the Portland Basin, Oregon and Washington.* (U.S.G.S. WRI Report 90-4196, p. 60)
RNSA (Roger N. Smith Associates, Inc.)	1997	Portland Well Field	*Expansion of Monitoring Well Network: Installation Summary Report* (Prepared for City of Portland Bureau of Water Works)

Notes:
U.S.G.S. = United States Geological Survey
WSP = Water-Supply Paper
DOGAMI = Department of Geology and Mineral Industries
WRI = Water Resources Investigations

Table 3-2
Hydrogeologic Unit Summary
Reynolds Metals Company - Troutdale, Oregon

Hydrogeologic Unit Name (a) (b)	Generalized Description	Depositional Setting	Estimated Unit Thickness (feet) (f)	Typical Yields (gpm) (c)	Present Beneath Site? (Y/N) (d)	Comments
Unconsolidated Sedimentary Aquifer (USA)	Gravel deposits, some boulders, with varying amounts of sand, silt, and clay.	Fluvial deposits: Late Pleistocene Columbia River catastrophic flood deposits and alluvial deposits from smaller tributaries.	Up to 250 onsite	5 - 6,000 (5-40 gpm for wells screened in clayey silt)	Yes	Unit generally recognizable in outcrop by lack of weathering beneath the oxidized upper 6 feet. Most RMC wells are likely screened in this unit.
Blue Lake Aquifer (same as USA)	Boulder, cobble, and gravel-sized clasts in a matrix of clayey to sandy silt. The coarse gravel includes 60-90 percent basalt and the rest is quartzite, granite, and diorite.	Fluvial deposits: Coarser-grained channel deposits of ancestral Columbia River.	60-220	Up to 10,000	No	Locally, unit is present beneath the eastern portion of the Portland Well Field, approximately 1 mile west of the RMC site.
Troutdale Gravel Aquifer (TGA)	Poorly to moderately cemented conglomerate and sandy conglomerate, and weakly to well-consolidated sandy gravel with sandstone lenses and beds. Upper portion weathered loess and soil.	Derived from ancestral Columbia River deposits and Cascade Range volcanic conglomerate and sandstone.	0-800 (but typically 100-400)	50 - 1,000	No	In many areas top of unit boundary is marked by cemented or clayey gravel. Likely removed by ancestral Columbia River erosion at site location.
Confining Unit 1 (CU1)	Siltstone and sandstone with some thin lenses of sandy tuffaceous silt and sandstone, and clay. Dark olive-gray to brown-gray sand and clay. Black sand or sandstone may occur in beds 5-15 ' thick.	Lacustrine (lake) bed deposits - SRM (e) and fine-grained portion of Troutdale Fm, deposited within a closed lacustrine basin.	Less than 200	Poor yield, but local sand lenses targeted by domestic wells.	No	Likely removed by ancestral Columbia River erosion at site location.
Troutdale Sandstone Aquifer (TSA)	Coarse grained sandstone and conglomerate with lenses and beds of fine to medium sand and thin to blue-gray silty clay. Basalt gravel conglomerate at base of unit.	Fluvial deposits of Ancestral Columbia River. Corresponds to coarser-grained portion of SRM and Troutdale Fm.	100-200	Up to 2,500	No	Unit thickest east of Sandy River closest to source area for sediments. Likely removed by ancestral Columbia River erosion at site location.

Table 3-2
Hydrogeologic Unit Summary
Reynolds Metals Company - Troutdale, Oregon

Hydrogeologic Unit Name (a) (b)	Generalized Description	Depositional Setting	Estimated Unit Thickness (feet) (f)	Typical Yields (gpm) (c)	Present Beneath Site? (Y/N) (d)	Comments
Confining Unit 2 (CU2)	Grayish olive-green clay and silt with lenses of silt and fine-to-medium grained basaltic sand. Claystone present near base of unit.	Lacustrine deposits - SRM and fine-grained portion of Troutdale Fm. Deposited within a closed lacustrine basin.	Less than 200 (averaging ~ 40-100)	Poor yield, lenses of silt and fine-grained sand 2-6' thick locally supply domestic wells.	No	Likely removed by ancestral Columbia River erosion at site location.
Sand and Gravel Aquifer (SGA)	Sand, gravel, silty sand, sand and clay. Upper portion may contain conglomerate with volcanic clasts in a sandy matrix overlain by sandstone. Generally fining downward.	Deposited by ancestral Columbia River - coarse grained sequence of SRM.	0-800 (~ 200 onsite)	5 - 3,000 (5-30 for domestic wells)	Yes	Some RMC wells appear to be screened in this unit.
Older Rocks	Lava flows and consolidated volcanic debris from the Rhododendron Fm, Columbia River Basalt Group (CRBG), and Skamania Volcanics. Also, marine sedimentary rocks: siltstone and sandstone.	Volcanic and marine sedimentary rocks.	Unknown	Typically low (5-10). Wells in CRB interflow zones- up to 1,000.	Yes	Marine rocks may contain saline water. CRBG used as source of water in upland areas where unit occurs at shallower depths. Outcrops at Ione Reef, just north of site.

Notes:
(a) Descriptions of hydrogeologic units in the RMC study area follow the informal hydrogeologic unit names adopted by Swanson (1993). One exception is the addition of the Blue Lake Aquifer as described by Hartford and McFarland, 1989. This unit is included within the Unconsolidated Sedimentary Aquifer by Swanson and McFarland, 1993.
(b) Hydrogeologic Units are presented from youngest (shallowest) to oldest (deepest).
(c) gpm = gallons per minute.
(d) "Beneath site" indicates area corresponding to Township 1 North (T1N), Range 3 East (R3E), Section 23.
(e) SRM = Sandy River Mudstone.
(f) Refer to Figure 3-1 for comparison of geologic units and aquifer units.

Table 3-3
Statistical Analyses of Silt Unit Hydraulic Test Results
Reynolds Metals Company - Troutdale, Oregon

Well #	Well Type	Well Location	Test Type	Analysis Method	Transmissivity (ft^2/min)	Aquifer Thickness (ft)	Estimated Hydraulic Conductivity (ft/min)	Estimated Hydraulic Conductivity (ft/day)	Log 10 Transformation
Slug Tests									
MW11-017	Shallow (silt)	East Potliner	Slug Test	Bower and Rice	0.0035	25	7.1E-05	0.20	-0.70
MW15-024	Shallow (silt)	Perimeter	Slug Test	Bower and Rice	0.0002	25	4.2E-06	0.01	-1.92
MW12-021	Shallow (silt)	Perimeter	Slug Test	Bower and Rice	0.0050	25	1.0E-04	0.29	-0.54
MW03-017	Shallow (silt)	Perimeter	Slug Test	Bower and Rice	0.0300	25	6.1E-04	1.7	0.24
MW05-025	Shallow (silt)	Perimeter	Slug Test	Bower and Rice	0.0350	25	7.1E-04	2.0	0.30
MW06-024	Shallow (silt)	Perimeter	Slug Test	Bower and Rice	0.0750	25	1.5E-03	4.3	0.64
MW02-024	Shallow (silt)	Scrap Yard	Slug Test	Bower and Rice	0.0223	25	4.5E-04	1.3	0.11
MW10-023	Shallow (silt)	South of Dike	Slug Test	Bower and Rice	0.0500	25	1.0E-03	2.9	0.46
MW07-024	Shallow (silt)	South of Dike	Slug Test	Bower and Rice	0.0775	25	1.6E-03	4.5	0.65
MW04-019	Shallow (silt)	South Wetlands	Slug Test	Bower and Rice	0.0011	25	2.3E-05	0.06	-1.19
MW18-016	Shallow (silt)	South Wetlands	Slug Test	Bower and Rice	0.0098	25	2.0E-04	0.56	-0.25
MW17-028	Shallow (silt)	South Wetlands	Slug Test	Bower and Rice	0.0245	25	5.0E-04	1.4	0.15
MW17-016	Shallow (silt)	South Wetlands	Slug Test	Bower and Rice	0.0925	25	1.9E-03	5.3	0.73
							Standard Deviation	**1.83**	**0.79**
							Arithmetic Mean	**1.89**	**-0.10**
Aquifer Thickness = 25 ft.							**Geometric Mean**	**0.79**	
Possible Outliers									
MW21-012	Shallow (silt)	North Landfill	Slug	Bower and Rice	0.5250	25	1.1E-02	30.24	1.48
MW01-019	Shallow (silt)	Along South Ditch	Slug	Bower and Rice	0.3472	25	7.1E-03	20	1.30

Table 3-4
Statistical Analyses of Upper Gray Sand Hydraulic Test Results
Reynolds Metals Company - Troutdale, Oregon

Well #	Well Type	Well Location	Test Type	Analysis Method	Transmissivity (ft^2/min)	Aquifer Thickness (ft)	Estimated Hydraulic Conductivity (ft/min)	Estimated Hydraulic Conductivity (ft/day)	Log10 Transformation
Slug Tests									
MW27-045	Shallow	Adjacent to Company Lake	Slug Test	Bower and Rice	0.6000	50	0.01200	17.28	1.24
MW38-035	Shallow	Along Salmon Creek	Slug Test	Bower and Rice	0.0900	50	0.00180	2.59	0.41
MW32-040	Shallow	Bakehouse	Slug Test	Bower and Rice	0.0600	50	0.00120	1.73	0.24
MW34-038	Shallow	East Potliner	Slug Test	Bower and Rice	0.0900	50	0.00180	2.59	0.41
MW31-034	Shallow	Fairview Farms	Slug Test	Bower and Rice	0.0900	50	0.00180	2.59	0.41
MW30-030	Shallow	Near Gresham Sand and Gravel	Slug Test	Bower and Rice	1.8600	50	0.03720	53.57	1.73
MW21-025	Shallow	North Landfill	Slug Test	Bower and Rice	0.3300	50	6.6E-03	9.50	0.98
MW08-027	Shallow	Perimeter	Slug Test	Bower and Rice	1.7014	50	3.4E-02	49.00	1.69
MW33-033	Shallow	Scrap Yard	Slug Test	Bower and Rice	1.5800	50	0.03160	45.50	1.66
MW29-033	Shallow	South of Dike	Slug Test	Bower and Rice	0.4700	50	0.00940	13.54	1.13
MW37-030	Shallow	South Wetlands	Slug Test	Bower and Rice	0.2300	50	0.00460	6.62	0.82
							Standard Deviation	**20.44**	**0.56**
							Arithmetic Mean	**18.59**	**0.97**
							Geometric Mean	**9.44**	
Short-Term Tests									
MW38-035	Shallow	Along Salmon Creek	Short Term	Confined Thies	0.0520	50	0.00104	**1.4976**	**0.18**
Possible Outliers									
MW35-038	Shallow	East Potliner	Slug Test	Bower and Rice	3.7300	50	0.07460	107.42	2.03
MW09-030	Shallow	North Landfill	Slug Test	Bower and Rice	3.4722	50	6.9E-02	100.00	2.00
MW25-035	Shallow	Scrap Yard	Slug Test	Bower and Rice	0.0013	50	2.6E-05	0.04	-1.43
MW18-031	Shallow	South Wetlands	Slug Test	Bower and Rice	0.0078	50	1.6E-04	0.22	-0.65
MW38-035	Shallow	Along Salmon Creek	Short Term	Recovery	0.0040	50	0.00008	0.1152	-0.94
MW38-035	Shallow	Along Salmon Creek	Short Term	Jacob	0.0240	50	0.00048	0.6912	-0.16

Table 3-5
Statistical Analyses of Intermediate Aquifer Hydraulic Test Results
Reynolds Metals Company - Troutdale, Oregon

Well #	Well Type	Well Location	Screened Materials	Test Type	Analysis Method	Transmissivity (ft^2/min)	Aquifer Thickness (ft)	Estimated Hydraulic Conductivity (ft/min)	Estimated Hydraulic Conductivity (ft/day)	Log10 Transformation
Slug Tests										
MW27-081	Intermediate	Adjacent to Company Lake	Sand	Slug Test	Bower and Rice	10.5800	100	0.10580	152.35	2.18
MW32-095	Intermediate	Bakehouse	Sand	Slug Test	Bower and Rice	14.1200	100	0.14120	203.33	2.31
MW31-095	Intermediate	Fairview Farms	Sand	Slug Test	Bower and Rice	8.3000	100	0.08300	119.52	2.08
MW30-100	Intermediate	Near Gresham Sand and Gravel	Sand	Slug Test	Bower and Rice	14.9600	100	0.14960	215.42	2.33
MW21-063	Intermediate	North Landfill	Sand	Slug Test	Bower and Rice	13.1000	100	0.13100	188.64	2.28
MW12-092	Intermediate	Perimeter	Sand	Slug Test	Bower and Rice	7.7000	100	0.07700	110.88	2.04
MW03-098	Intermediate	Perimeter	Sand	Slug Test	Bower and Rice	11.2800	100	0.11280	162.43	2.21
MW15-086	Intermediate	Perimeter	Sand	Slug Test	Bower and Rice	11.5200	100	0.11520	165.89	2.22
MW33-095	Intermediate	Scrap Yard	Sand	Slug Test	Bower and Rice	10.8800	100	0.10880	156.67	2.19
MW06-094	Intermediate	South of Dike	Sand	Slug Test	Bower and Rice	8.3200	100	0.08320	119.81	2.08
MW29-090	Intermediate	South of Dike	Sand	Slug Test	Bower and Rice	11.5200	100	0.11520	165.89	2.22
MW10-090	Intermediate	South of Dike	Sand	Slug Test	Bower and Rice	11.8400	100	0.11840	170.50	2.23
								Standard Deviation	**31.20**	**0.09**
								Arithmetic Mean	**160.94**	**2.20**
								Geometric Mean	**157.81**	
Short-Term Tests										
MW27-081	Intermediate	Adjacent to Company Lake	Sand	Short-Term Test	Confined Cooper-Jacob	5.1170	100	0.05117	73.68	1.87
MW27-081	Intermediate	Adjacent to Company Lake	Sand	Short-Term Test	Confined Thies Recovery	12.1500	100	0.12150	174.96	2.24
MW27-081	Intermediate	Adjacent to Company Lake	Sand	Short-Term Test	Confined Thies	12.8700	100	0.12870	185.33	2.27
MW32-095	Intermediate	Bakehouse	Sand	Short-Term Test	Confined Thies	5.9230	100	0.05923	85.29	1.93
MW32-095	Intermediate	Bakehouse	Sand	Short-Term Test	Confined Cooper-Jacob	7.8250	100	0.07825	112.68	2.05
MW32-095	Intermediate	Bakehouse	Sand	Short-Term Test	Confined Thies Recovery	12.0800	100	0.12080	173.95	2.24
MW06-094	Intermediate	South of Dike	Sand	Short-Term Test	Confined Thies Recovery	15.2500	100	0.15250	219.60	2.34
MW06-094	Intermediate	South of Dike	Sand	Short-Term Test	Confined Cooper-Jacob	3.0700	100	0.03070	44.21	1.65
MW06-094	Intermediate	South of Dike	Sand	Short-Term Test	Confined Thies	3.6700	100	0.03670	52.85	1.72
								Standard Deviation	**61.08**	**0.24**
								Arithmetic Mean	**124.73**	**2.03**
		Aquifer thickness = 100 ft.						**Geometric Mean**	**108.30**	**2.02**
Fairview Farms Aquifer Test										
FFT01	Intermediate	Fairview Farms	Sand	FF04/Datalogger	Recovery Theis	38.1700	300	0.12723	183.22	2.26
FFT01	Intermediate	Fairview Farms	Sand	FF04/Datalogger	Papadopulos-Cooper	38.2900	300	0.12763	183.79	2.26
FFT01	Intermediate	Fairview Farms	Sand	FF04/Datalogger	Confined Cooper Jacob	40.8200	300	0.13607	195.94	2.29
FFT01	Intermediate	Fairview Farms	Sand	FF04/Datalogger	Confined Theis	41.3200	300	0.13773	198.34	2.30
								Standard Deviation	**6.87**	**0.02**
								Aritmetic Mean	**190.32**	**2.28**
								Geometric Mean	**190.20**	**2.28**

Table 3-6
Statistical Analyses of Deep Aquifer Hydraulic Test Results
Reynolds Metals Company - Troutdale, Oregon

Well #	Well Type	Well Location	Screened Materials	Test Type	Analysis Method	Transmissivity (ft^2/min)	Aquifer Thickness (ft)	Estimated Hydraulic Conductivity (ft/min)	Estimated Hydraulic Conductivity (ft/day)	Log10 Transformation
Eastern Half of Site										
MW10-165	Deep	South of Dike	Sand	Short-Term Test	Confined Theis	2.4600	200	0.01230	18	1.25
MW10-165	Deep	South of Dike	Sand	Short-Term Test	Confined Cooper Jacob	5.3440	200	0.02672	38	1.59
MW10-165	Deep	South of Dike	Sand	Short-Term Test	Recovery Theis	12.4800	200	0.06240	90	1.95
								Standard Deviation	**30.32**	**0.29**
								Arithmetic Mean	**48.68**	**1.60**
								Geometric Mean	**39.42**	**1.57**
MW21-176	Deep	North Landfill	Sand/Gravel	Slug Test	Bower and Rice	18.8889	200	0.09444	136	2.13
MW10-165	Deep	South of Dike	Sand/Gravel	Slug Test	Bower and Rice	10.9722	200	0.05486	79	1.90
MW33-165	Deep	Scrap Yard	Sand/Gravel	Slug Test	Bower and Rice	17.4800	200	0.08740	126	2.10
								Standard Deviation	**24.83**	**0.10**
								Arithmetic Mean	**113.62**	**2.04**
								Geometric Mean	**110.58**	**2.04**
MW21-176	Deep	North Landfill	Sand/Gravel	PW3&7/Hand/Corrected	Papadopulos-Cooper	8.7850	300	0.02928	42.17	1.62
MW21-176	Deep	North Landfill	Sand/Gravel	PW3&7/Hand/Corrected	Confined Theis	9.0110	300	0.03004	43.25	1.64
MW21-176	Deep	North Landfill	Sand/Gravel	PW3&7/Hand/Corrected	Confined Cooper Jacob	18.8200	300	0.06273	90.34	1.96
MW33-165	Deep	Scrap Yard	Sand/Gravel	PW3&7 DL	Papadopulos-Cooper	44.6700	300	0.14890	214.42	2.33
MW33-165	Deep	Scrap Yard	Sand/Gravel	PW3&7 DL	Confined Theis	45.7800	300	0.15260	219.74	2.34
MW33-165	Deep	Scrap Yard	Sand/Gravel	PW3&7 DL	Confined Cooper Jacob	24.6400	300	0.08213	118.27	2.07
								Standard Deviation	**72.67**	**0.29**
								Arithmetic Mean	**121.36**	**1.99**
								Geometric Mean	**98.59**	**1.97**

Table 3-6
Statistical Analyses of Deep Aquifer Hydraulic Test Results
Reynolds Metals Company - Troutdale, Oregon

Well #	Well Type	Well Location	Screened Materials	Test Type	Analysis Method	Transmissivity (ft^2/min)	Aquifer Thickness (ft)	Estimated Hydraulic Conductivity (ft/min)	Estimated Hydraulic Conductivity (ft/day)	Log10 Transformation
Site Center										
MW27-176	Deep	Adjacent to Company Lake	Sand/Gravel	Short-Term Test	Recovery Theis	2.1470	200	0.01074	15.458	1.19
MW27-176	Deep	Adjacent to Company Lake	Sand/Gravel	Short-Term Test	Confined Theis	4.2340	200	0.02117	30.485	1.48
MW03-175	Deep	Perimeter	Sand	Short-Term Test	Confined Cooper Jacob	4.6770	200	0.02339	33.674	1.53
MW03-175	Deep	Perimeter	Sand	Short-Term Test	Confined Theis	7.9870	200	0.03994	57.506	1.76
								Standard Deviation	15.07	0.20
								Arithmetic Mean	34.28	1.49
								Geometric Mean	30.91	1.48
MW27-176	Deep	Adjacent to Company Lake	Sand/Gravel	Slug Test	Bower and Rice	20.4167	200	0.10208	147	2.17
MW28-160	Deep	Bakehouse	Sand	Slug Test	Bower and Rice	25.7200	200	0.12860	185	2.27
MW32-165	Deep	Bakehouse	Sand	Slug Test	Bower and Rice	26.6000	200	0.13300	192	2.28
MW03-175	Deep	Perimeter	Sand	Slug Test	Bower and Rice	23.7500	200	0.11875	171	2.23
								Standard Deviation	17.10	0.04
								Arithmetic Mean	173.68	2.24
								Geometric Mean	172.80	2.24
MW28-160	Deep	Bakehouse	Sand	PW3&7 DL	Papadopulos-Cooper	35.3500	300	0.11783	169.68	2.23
MW28-160	Deep	Bakehouse	Sand	PW3&7 DL	Confined Theis	31.4700	300	0.10490	151.06	2.18
MW28-160	Deep	Bakehouse	Sand	PW3&7 DL	Confined Cooper Jacob	23.3400	300	0.07780	112.03	2.05
MW32-165	Deep	Bakehouse	Sand	PW3&7 DL Cor	Papadopulos-Cooper	22.0400	300	0.07347	105.79	2.02
MW32-165	Deep	Bakehouse	Sand	PW3&7 DL Cor	Confined Theis	24.1700	300	0.08057	116.02	2.06
MW32-165	Deep	Bakehouse	Sand	PW3&7 DL Cor	Confined Cooper Jacob	23.1200	300	0.07707	110.98	2.05
MW32-165	Deep	Bakehouse	Sand	FF04/Datalogger	Papadopulos-Cooper	28.8200	300	0.09607	138.34	2.14
MW32-165	Deep	Bake house	Sand	FF04/Datalogger	Confined Theis	25.1100	300	0.08370	120.53	2.08
MW32-165	Deep	Bakehouse	Sand	FF04/Datalogger	Confined Cooper Jacob	48.3800	300	0.16127	232.22	2.37
MW03-175	Deep	Perimeter	Sand	FF04/Datalogger	Papadopulos-Cooper	17.3300	300	0.05777	83.18	1.92
MW03-175	Deep	Perimeter	Sand	FF04/Datalogger	Confined Theis	19.4200	300	0.06473	93.22	1.97
MW03-175	Deep	Perimeter	Sand	PW3&7 DL	Papadopulos-Cooper	37.6200	300	0.12540	180.58	2.26
MW03-175	Deep	Perimeter	Sand	PW3&7 DL	Confined Theis	36.2700	300	0.12090	174.10	2.24
MW03-175	Deep	Perimeter	Sand	PW3&7 DL	Confined Cooper Jacob	24.7000	300	0.08233	118.56	2.07
								Standard Deviation	39.41	0.12
								Arithmetic Mean	136.16	2.12
								Geometric Mean	130.99	2.11

Table 3-6
Statistical Analyses of Deep Aquifer Hydraulic Test Results
Reynolds Metals Company - Troutdale, Oregon

Well #	Well Type	Well Location	Screened Materials	Test Type	Analysis Method	Transmissivity (ft^2/min)	Aquifer Thickness (ft)	Estimated Hydraulic Conductivity (ft/min)	Estimated Hydraulic Conductivity (ft/day)	Log10 Transformation
Western Site and Fairview Farms										
MW15-175	Deep	Perimeter	Sand	Slug Test	Bower and Rice	5.4000	200	0.02700	39	1.59
MW12-184	Deep	Perimeter	Sand	Slug Test	Bower and Rice	9.2400	200	0.04620	67	1.82
MW06-176	Deep	South of Dike	Gravel	Slug Test	Bower and Rice	16.7600	200	0.08380	121	2.08
								Standard Deviation	33.97	0.20
								Arithmetic Mean	75.36	1.83
								Geometric Mean	67.83	1.82
FF06	Deep	Fairview Farms	Sand/Gravel	FF04/Datalogger	Papadopulos-Cooper	26.4100	300	0.08803	126.77	2.10
FF06	Deep	Fairview Farms	Sand/Gravel	FF04/Datalogger	Confined Theis	27.5200	300	0.09173	132.10	2.12
FF06	Deep	Fairview Farms	Sand/Gravel	FF04/Datalogger	Confined Cooper Jacob	34.5500	300	0.11517	165.84	2.22
FF04	Deep	Fairview Farms	Gravel in SGA	FF04/Datalogger	Recovery Theis	37.4800	300	0.12493	179.90	2.26
MW12-184	Deep	Perimeter	Sand	FF04/Hand	Papadopulos-Cooper	17.4000	300	0.05800	83.52	1.92
MW12-184	Deep	Perimeter	Sand	FF04/Hand	Confined Theis	19.8400	300	0.06613	95.23	1.98
MW12-184	Deep	Perimeter	Sand	FF04/Hand	Confined Cooper Jacob	29.7500	300	0.09917	142.80	2.15
MW12-184	Deep	Perimeter	Sand	FF04/Hand	Recovery Theis	39.0800	300	0.13027	187.58	2.27
MW15-175	Deep	Perimeter	Sand	FF04/Datalogger	Papadopulos-Cooper	31.0000	300	0.10333	148.80	2.17
MW15-175	Deep	Perimeter	Sand	FF04/Datalogger	Confined Theis	31.2200	300	0.10407	149.86	2.18
MW15-175	Deep	Perimeter	Sand	FF04/Datalogger	Confined Cooper Jacob	29.2200	300	0.09740	140.26	2.15
MW15-175	Deep	Perimeter	Sand	FF04/Datalogger	Recovery Theis	34.3800	300	0.11460	165.02	2.22
MW06-176	Deep	South of Dike	Gravel	FF04/Datalogger	Papadopulos-Cooper	31.6400	300	0.10547	151.87	2.18
MW06-176	Deep	South of Dike	Gravel	FF04/Datalogger	Confined Theis	30.7800	300	0.10260	147.74	2.17
MW06-176	Deep	South of Dike	Gravel	FF04/Datalogger	Confined Cooper Jacob	34.1600	300	0.11387	163.97	2.21
MW06-176	Deep	South of Dike	Gravel	FF04/Datalogger	Recovery Theis	44.2000	300	0.14733	212.16	2.33
								Standard Deviation	30.90	0.10
								Arithmetic Mean	149.59	2.16
								Geometric Mean	146.06	2.16

Table 3-6
Statistical Analyses of Deep Aquifer Hydraulic Test Results
Reynolds Metals Company - Troutdale, Oregon

Well #	Well Type	Well Location	Screened Materials	Test Type	Analysis Method	Transmissivity (ft^2/min)	Aquifer Thickness (ft)	Estimated Hydraulic Conductivity (ft/min)	Estimated Hydraulic Conductivity (ft/day)	Log10 Transformation
Possible Outliers										
FF04	Deep	Fairview Farms	Gravel in SGA	FF04/Datalogger	Papadopulos-Cooper	4.2600	300	0.01420	20.45	1.31
FF04	Deep	Fairview Farms	Gravel in SGA	FF04/Datalogger	Confined Theis	14.4400	300	0.04813	69.31	1.84
FF04	Deep	Fairview Farms	Gravel in SGA	FF04/Datalogger	Confined Cooper Jacob	6.4970	300	0.02166	31.19	1.49
MW27-176	Deep	Adjacent to Company Lake	Gravel	Short-Term Test	Confined Cooper Jacob	0.3490	200	0.00175	2.513	0.40
MW32-165	Deep	Bakehouse	Sand	FF04/Datalogger	Recovery Theis	56.6500	300	0.18883	271.92	2.43
MW08-169	Deep	Perimeter	Gravel	Short-Term Test	Recovery Theis	0.0066	200	0.00003	0.048	-1.32
MW08-169	Deep	Perimeter	Gravel	Short-Term Test	Confined Cooper Jacob	0.0910	200	0.00046	0.655	-0.18
MW08-169	Deep	Perimeter	Gravel	Short-Term Test	Confined Theis	0.1040	200	0.00052	0.749	-0.13
MW03-175	Deep	Perimeter	Sand	Short-Term Test	Recovery Theis	42.1600	200	0.21080	303.552	2.48
MW03-175	Deep	Perimeter	Sand	FF04/Datalogger	Confined Cooper Jacob	75.9500	300	0.25317	364.56	2.56
MW29-179	Deep	South of Dike	Gravel	Slug Test	Bower and Rice	0.4170	200	0.00209	3.00	0.48

Table 3-7
Physical Parameters Data Summary for HSA Soil Samples Collected During Summer 1998
Reynolds Metals Company--Troutdale, Oregon

Station ID	Sampling Date	Approx. Depth or Sample interval	Specific Gravity	Organic Matter Content (b)		Falling Head (Fixed Wall) Test (c) Sand Matrix					Triaxial (Flexible Wall) Test (d) Silt Matrix							Triaxal Compression Test - Saturation Data (d)		
				Moisture Content	Organic Content	Wet Density (AT)	Dry Density (AT)	Porosity (AT)	Vertical Hydraulic Conductivity (e)		Wet Density (BT)	Dry Density (BT)	Wet Density (AT)	Dry Density (AT)	Porosity (AT)	Vertical Hydraulic Conductivity (e)		Cell Pressure	Back Pressure	B
		(ft bgs)	(a)	%	%	PCF	PCF	%	cm/sec	ft/day	PCF	PCF	PCF	PCF	%	cm/sec	ft/day	PSI	PSI	(f)
South Landfill Area																				
SL-SB61-005	6/23/98	6.5 to 7	2.68	19.1	1.0	122.7	99.5	37.1	1.6E-03	4.5										
SL-SB61-017	6/23/98	19 to 21	2.77	42.8	2.6						110.9	76.8	118.5	86.9	50.60	9.8E-08	2.8E-04	50	38.0	1.00
SL-SB61-045	6/23/98	45.5 to 46	2.69	20.3	0.7	124.3	101.6	36.21	1.5E-03	4.4										
East Potliner Area																				
EP-SB01-014	6/24/98	14 to 16	2.72	37.3	1.4						119.3	92.8	140.7	112.3	45.39	2.2E-07	6.2E-04	50	38.0	0.99
EP-SB01-040	6/24/98	42 to 42.5	2.69	20.7	0.6	126.4	101.7	39.64	1.5E-03	4.3										
Scrap Yard Area																				
SY-SB10-005	6/24/98	6 to 6.5	2.74	14.4	0.5	127.7	108.5	30.79	5.6E-04	1.6										
SY-SB10-017	6/24/98	21 to 23	2.71	38.6	2.2						114.5	81.6	121.6	89.9	50.81	1.4E-07	3.9E-04	50	38	0.99
SY-SB10-035	6/24/98	39 to 39.5	2.69	21.9	0.7	121.8	95.0	42.87	1.7E-03	4.7										
SY-SB11-005	6/24/98	7 to 9	2.73	41.2	2.1						108.7	77.4	115.8	81.5	54.91	2.0E-06	5.8E-03	60	48	0.97
SY-SB11-040	6/24/98	40.5 to 41	2.71	22.8	0.5	126.8	98.2	45.89	4.2E-03	11.9										

Notes:
(a) Specific gravity by ASTM D 854.
(b) Organic Matter Content (Physical) by ASTM D 2974.
(c) Permeability Test - Falling Head by COE Method. (AT) = After test.
(d) Triaxial, Back Pressure Permeability/Compatibility Testing TX/PBP, ASTM D 5084. (BT) = Before test, (AT) = After test.
(e) Vertical hydraulic conductivity is average of values from Falling Head Fixed Wall Test and Triaxial, or Flexible Wall Test.
(f) B (bar) = pore pressure change/total stress change.

ft bgs = feet below ground surface.
% = percent.
PCF = pounds per cubic foot.
PSI = pounds per square inch.

Table 3-8
Estimated Mixing Factors for Groundwater Discharge to the Columbia River
Reynolds Metals Company - Troutdale, Oregon

River Flow Condition	Mixing Factor Based on Portion of River Flow Available for Mixing		
	20 Percent	40 Percent	50 Percent
7Q10	34,000	67,000	84,000
Minimum Monthly	46,000	92,000	115,000
Mean Annual	75,000	150,000	188,000

Table 3-9
Estimated Mixing Factors for Groundwater Discharge to the Sandy River
Reynolds Metals Company - Troutdale, Oregon

River Flow Condition	Mixing Factor Based on Portion of River Flow Available for Mixing		
	10 Percent	25 Percent	50 Percent
7Q10	90	220	450
Minimum Monthly	200	490	990
Mean Annual	870	2,200	4,400

Table 3-10
Well Construction Summary for Offsite Wells Located Within 1-Mile Radius of RMC Facility
Reynolds Metals Company - Troutdale, Oregon

Well Inventory No.	Well Location (by 1/4-1/4 Section)	Original Well Owner	Date Completed	Original Well Use (a)	Total Well Depth (b)	Well Yield (gpm) (c)	Static Water Level from Original Well Report (ft bgs)	Screened or Perforated Interval (ft bgs)	Water-Bearing Material and Comments
T1N R3E									
	Section 14								
1	14cc	Sundial Marine Tug & Barge	Dec. 1979	D	233	60	25	228 - 233	Sand and gravel at 222' bgs.
2	14ccad	Gresham Sand & Gravel *(formerly Harris Quade)*	Nov. 1967	D	127	60	30	120 - 130	Sand, fine with gravel - med. and coarse; sand fine, gray, and black.
	Section 22								
3	22adcc	Fairview Farms Inc. Well # 6	1950	D, I, Mn	200	1,200	17	119 - 200	Fine gray clay; well formerly used for irrigation of 170 acres. Owned by RMC.
4	22 ?	A. H. Harding	Apr. 1963	D	98 - Backfilled *from 103 bgs.*	18	30	93 - 98	Gray sand. Well loc. = 150' No. and 50' E. *of the SW corner of tax lot no. 14.*
	Section 23								
5	23abcd	Bonneville Power Admin. *(BPA)* Well # 1	1946	In.	183	142	10.3	NA	Sand and gravel from 175 - 183'. Chem. analysis avail. Currently **not in use.**
6	23acaa	BPA Well # 2	Jan. 1947	In	287	500	36	171 - 183 199 - 206 265 - 283	Sand and gravel from all 3 perforated zones. Not used for potable at substation. Hand washing etc.; drinking water is bottled.
7	23bcc	Fairview Farms Inc. Well # 4	1943	D, I, Mn	281	700	11	237 - 250	Sand and gravel. Owned by RMC. Formerly used for irrigation.
8	23dc	Port of Portland *Troutdale Airport loc.*	June 1961	M	750	800	20	435 - 738	Sand and gravel aquifer. Well currently not in use.
9	23 ?	Michael A. Lacey	Dec. 1976	D	121	18	18	None, Cased to 113 bgs	Gray loose sand. Gray sand and gravel.
10	23 ?	Barry Stevens	**VOID.** Well location incorrect on well log. County assessors office shows well in Township T1 S, not T1N.						
	Section 24								
11	24 ?	James Graham	Mar. 1964	D	170	15 - 20	25	None, Cased to 170 bgs	Sand and gravel.
	Section 25								
12	25cbc	City of Troutdale Well # 4 (Shop Well)	Aug. 1980	M	571	590	118	493 - 563	Sand, silt and gravel Aquifer = SGA.
13	25 ?	Darrel J. Muyskins	Feb. 1967	D	115	20	15	None, Cased to 115 bgs	High iron water at 100' bgs - cased off. Coarse sand and gravel.
14	25 ?	Roy Holmberg	Apr. 1974	T	110	20	38	105 - 110	Sandstone. Test well for restaurant.

Table 3-10
Well Construction Summary for Offsite Wells Located Within 1-Mile Radius of RMC Facility
Reynolds Metals Company - Troutdale, Oregon

Well Inventory No.	Well Location (by 1/4-1/4 Section)	Original Well Owner	Date Completed	Original Well Use (a)	Total Well Depth (b)	Well Yield (gpm) (c)	Static Water Level from Original Well Report (ft bgs)	Screened or Perforated Interval (ft bgs)	Water-Bearing Material and Comments
	Section 26								
15	26ccd	Board of County Commissioners	Mar. 1940	D, I	228	500	67	None, Cased to 228 bgs	Clay and gravel.
16	26ad	M.A. Cerruti	Jun. 1967	D	110 - Backfilled from 115 bgs	35	25	None, Cased to 110 bgs	Fine gravel.
17	26db	Wayne Lawrey	Apr. 1967	D	54	35	20	None, Cased to 54 bgs	Water bearing from 50 - 54' bgs. - loose gravel.
18	26 ?	W. McGinnis	Nov. 1956	D	41	45	NA	NA	Boulders and gravel.
19	26ca	James Dreiling	Mar. 1976	D	52	12	24	None, Cased to 52 bgs	Gravel, large.
20	26cc	Multnomah County Farm	NA	D, I	228 - Backfilled from 257 bgs	500	65	NA	Cemented gravel - Troutdale Fm. from 195 - 228' bgs.
21	26 ?	Standard Oil Co.	Jun. 1971	D	52	36	3	31 - 47	Sandy gravel, coarse brown.
22	26 ?	A.E. Sanderson	Jan. 1971	D	109 - Backfilled from 111 bgs	40	70	99 - 110	Cemented gravel, some loose water-producing gravel, gray clay binder.
23	26 ?	L.S. Klinger	Oct. 1970	D	250	40	40	210 - 250	Blue fine sand, cemented gravel.
24	26 ?	L.W. Arndt	Mar. 1967	D	60	15	3	51 - 60	High silica water at 47' bgs in gravel and sand zone - cased off. Water in cemented gravel.
25	26 ?	Mrs. Weir Owens	Nov. 1956	D	52	15	NA	NA	Boulders, sand, and gravel.
26	26 ?	Reynolds Troutdale Federal C.U.	5/1/60	D	36	40	3	None - Cased to 36 bgs	Gravel.
27	26db	Glen Elswork Oakes	Jul. 1955	I	94	20	77	None - Cased to 94 bgs	Gravel at 90 - 94' bgs. However, location uncertain.
28	26db	James G. Simoni	1945	I	50	45	10	None - Cased to 50	GW permit No. GR2773.
29	26 ?	West Coast Alloys	Jun. 1974	In	23	100	8	NA	Medium gravel.
30	26 ?	West Coast Alloys	Apr. 1961	In	80	30	20	50 - 80	Sand stoned gravel.

Table 3-10

Well Construction Summary for Offsite Wells Located Within 1-Mile Radius of RMC Facility

Reynolds Metals Company - Troutdale, Oregon

Well Inventory No.	Well Location (by 1/4-1/4 Section)	Original Well Owner	Date Completed	Original Well Use (a)	Total Well Depth (b)	Well Yield (gpm) (c)	Static Water Level from Original Well Report (ft bgs)	Screened or Perforated Interval (ft bgs)	Water-Bearing Material and Comments
	Section 27								
31	27cbbb	City of Fairview Well # 3	Aug. 1956	M	1,060	400	60	275 - 340	SGA aquifer - cemented gravel. Reperforated in 1958.
32	27cabb	City of Fairview New well # 6	Jul. 1992	M	314 - Backfilled from 322 bgs	500	102	201 - 216 236 - 256 265 - 301	Well at 199 St. - TSA Aquifer. Gravel - gray brn. tan w/sand mica layers of loosely cemented sand and gravel. Large cobbles and cemented gravel.
33	27adb	Fairview Farms Inc. Well # 5	1940	D, I, Mn	275	400	35	53 - 61 65 - 75 195 - 220 240 - 263	Irrigation of 110 acres.
34	27ad	Fairview Farms Inc. Well # 2	1939	D, I, Mn	408	200	30	66 - 83	Irrigation of 2 acres.
35	27addc	Fairview Farms Inc. Well # 1	1954	D, I, Mn	182	100	NA	139 - 150	Gravel at 137 - 150' bgs. Irrigation of 10 acres.
36	27dc	Gordon Cousey	May 1971	D	72	20	10	None (cased to 67)	Sand and gravel, occasional boulders - TGA aquifer.
37	27bd	Townsend	1939	- I, Dairy	60	150	25	Unknown	Sandy loam, sand rock, gravel
38	27dacc	Wood Village Well # 3	1980	M	300	700-800	78	200-230 245-255	Sand and gravel. Sand and gravel.

Notes:

1. Well log information compiled from original Water Well Report forms collected from Oregon Water Resources Department, Salem, Oregon, and from a literature review from McCarthy and Anderson, 1990.
2. Refer to Figure 3-21 for approximate well locations and to Appendix D in Volume 3 for well logs.

(a) Original Well Use:
D = Domestic; M = Municipal; P = Production Wells
I = Irrigation; Mn = Manufacturing; T = Test

(b) ft bgs = feet below ground surface.

(c) Well yield reported in gallons per minute.
Yield value from pumping (air test, boiler test, etc.) test rate performed after well completion.

Abbreviations:

bgs = below ground surface.
gpm = gallons per minute.
NA = Information not available.
SGA = Sand and Gravel Aquifer.
TSA = Troutdale Sandstone Aquifer.
TGA = Troutdale Gravel Aquifer.
* Static Water level for February 2, 1995.

Table 3-11
Groundwater Rights Summary for Offsite Wells Located In Township 1 North, Range 3 East, Sections 14, 15, 22, 23, and 24
Reynolds Metals Company - Troutdale, Oregon

Well Inventory Number (a)	Owner or Agency	Permit No.	Priority Date	1/4-1/4 Section	Original Use (b)	Category (c)	Rate (gpm)	P/A (d)	Legal Description
T1N, R3E, Section 22									
3	Fairview Farms Well # 6	GR 1589	12/31/50	SENE	ID / IM	3 / 4	1,200	P/A	3,000 ft., N. from cor, Sec 22, 23, 26 and 27
T1N, R3E, Section 23									
7	Fairview Farms Well # 4	GR 1587	12/31/43	SWNW	IM / ID	4 / 3	700	A / P	2,300 ft., N. from cor, Sec 22, 23, 26 and 27
5	BPA Well # 1	GR 3796	1/31/47	NWNE	IM	4	440	P	N. 27 degrees 34 min., 10 sec. W. 4,642 ft., from SE cor, Sec 23.

Notes:

(a) Refer to Table 3-10 for corresponding Well Inventory Number.
Groundwater use permits are not required for single or group domestic use wells or yields of less than 15,000 gallons per day.
(b) Original Use: ID = Domestic; IM = Manufacturing
(c) Category: 3 = Irrigation 4 = Industrial Use
(d) P/A: P = Primary Source A = Alternate Source

Abbreviations:
T1N = Township 1 North.
R3E = Range 3 East.
gpm = gallons per minute.
BPA = Bonneville Power Administration.

SECTION 4

Nature and Extent of Constituents of Potential Concern

SECTION 4

Nature and Extent of Constituents of Potential Concern

This section presents a discussion and summary of the nature and extent of constituents of potential concern in groundwater at the RMC site.

4.1 Potential Source Areas

The following sections provide a brief description of plant operations and a summary of past waste disposal practices potentially affecting groundwater quality. This information is used along with site characterization data to identify potential source areas and constituents of potential concern.

4.1.1 Summary of Plant Operations Potentially Impacting Groundwater

The RMC Troutdale plant uses what is known as the "prebake" method of producing aluminum. Carbon anodes are produced at the facility's carbon plant from green carbon paste (a mixture of calcined petroleum coke, coal tar pitch, and the crushed remains of spent carbon anodes). Green carbon paste is an in-process material that is mixed and pressed into carbon block form the day it is made. The anodes are formed and then baked in underground pits in the bakehouse. Copper rods are attached to steel stubs, cast into the baked anodes, to suspend the anodes in carbon-lined cells (known as pots). This carbon pot lining acts as the cathode and is made of anthracite coal, coal tar pitch, and graphite blocks.

Reduction takes place when electricity is passed from the anode to the cathode through an electrolyte solution of molten cryolite (Na_2AlF_6) and alumina. As the alumina is reduced, the aluminum is separated and settles to the bottom of the pot. At regular intervals, the molten aluminum is siphoned or tapped off and taken to the casthouse, where it is made into sheet or foundry ingots of varying sizes. Other metals such as copper, beryllium, and chromium are added in the furnaces to produce various aluminum alloys. Alumina is stored in bulk in steel storage silos. Cryolite and chromium are purchased in bag form and stored indoors. Beryllium is stored indoors in steel drums, while scrap copper is sometimes stored outdoors at the casthouse, Building 97 subarea, or on the south side of scrap yard.

After continued use, the carbon potliners fail and the molten aluminum either leaks from the pots or becomes contaminated with iron from the steel shell or conductors. Cracked or "spent" potliners are broken out of the pots and replaced. Spent potliners contain significant amounts of iron cyanide and free cyanide (Federal Register 177:35416, September 13, 1988) and are listed as hazardous waste by the U.S. Environmental Protection Agency [Resource Conservation and Recovery Act (RCRA) K088 waste; 40 *Code of Federal Regulations* (CFR) 261.32].

4.1.2 Summary of Past Waste Disposal Practices Potentially Affecting Groundwater

A number of wastes are generated at the RMC plant during the production of aluminum. Twenty-one separate waste streams were identified by RMC in response to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) information needs letter. These 21 waste streams originate in the carbon plant, pot rooms, casthouse, and wastewater treatment plant, or at sites of miscellaneous plant operations. The 21 waste streams are listed in Table 4-1, along with the estimated quantity generated annually at full operation, and the disposition of the waste.

RMC conducted leaching tests on waste refractory brick as part of the AWARE (avoid waste and reduce emissions) program. Results indicated leaching or particulate contribution from the brick along the COE dike appears to be an insignificant source to Company Lake sediment or interstitial soil. Fluoride and metals may leach to groundwater, but concentrations are expected to be insignificant in comparison to the potential leaching from Company Lake sediment. For a more detailed discussion of brick leach testing, refer to Section 4.5.2 of *Technical Memorandum DS No. 15: Company Lake Supplemental Data Summary* (CH2M HILL, March 26, 1997).

4.1.3 Identification of Potential Source Areas

On the basis of information collected during sitewide and individual soil and debris area investigations and routine groundwater monitoring activities (see Section 2), 10 of these soil and debris areas were identified as potential source areas for the RMC site. Figure 1-2 shows soil and debris area locations. Table 4-2 summarizes these soil and debris areas and their groundwater constituent characteristics. Table 4-3 summarizes maximum contaminant level (MCL) exceedances in groundwater for wells sampled in these areas in 1997 and 1998.

On the basis of the 1997 and 1998 groundwater monitoring results, nine constituents exceeded primary MCLs: arsenic (total and dissolved), beryllium (total and dissolved), chromium (total), nickel (total), lead (total), fluoride, cyanide, 1,1-dichloroethene (1,1-DCE), and tetrachlorethene (PCE). These exceedances are generally consistent with previous monitoring results.

4.2 Constituents of Potential Concern in Groundwater

Background concentrations and constituents of potential concern in groundwater will be identified in the baseline risk assessment, to be completed in summer 1999. A determination of remedial goals for groundwater will be made in the Record of Decision (ROD). In the meantime, MCLs have been used as a benchmark for preliminary assessment of groundwater conditions at the site. Pending the baseline risk assessment and final cleanup goals, fluoride is considered the predominant constituent of potential concern because of its distribution and presence above the MCL (4 mg/L). With the few exceptions noted later in this section, other constituents [metals, cyanide, and volatile organic compounds (VOCs)] detected above the MCL are co-located with fluoride.

The following subsections provide (1) a brief description of the current distribution of fluoride, metals, cyanide, and VOCs in exceedance of MCLs across the site, and (2) a synopsis of time-concentration trends by hydrogeologic unit [silt, upper gray sand (UGS), intermediate-depth sand, deep sand/gravel] from June 1994 through August 1998.

4.2.1 Fluoride

4.2.1.1 Horizontal Distribution of Fluoride in Groundwater

This discussion of the sitewide distribution of fluoride is based on the 1998 fluoride concentration contour maps, which were constructed using both 1997 and 1998 fluoride data. The use of data collected over this time period for constructing the distribution maps is considered a reasonable approach due to the small variation seen in fluoride concentrations over time. Figures 4-1 through 4-4 depict the current horizontal distribution of fluoride by hydrogeologic area (silt, upper gray sand, intermediate-depth sand, and deep sand/gravel). The reader is referred to the *1998 Annual Groundwater Monitoring Report* (CH2M HILL, March 1999) to review both 1997 and 1998 fluoride distribution maps.

Silt Unit. Fluoride concentrations above the MCL in shallow monitoring wells screened in the silt unit appear localized to the southern portion of the site (see Figure 4-1). Shallow fluoride concentrations north of the dike in the vicinity of the north landfill are presented in Figure 4-2 (UGS), which shows that little or no silt is present in this area.

General Observations–Silt Unit.

- Three of the areas with fluoride concentrations exceeding 45 mg/L correlate well with the locations of known soil and debris areas with high fluoride content in surface materials: east potliner (MW11-017), scrap yard (MW13-022), and south landfill (MW19-013 and MW26-012).
- The MW04-019 concentration of 90.3 mg/L is probably a result of (1) installation of the well in low-permeability sediment (silt) and (2) process residue in the Building 97 subarea of south wetlands. The elevated fluoride concentration in groundwater at this location appears to be localized.
- South Ditch monitoring well MW36-006 routinely exhibits high fluoride concentrations (ranging between 94.9 and 120 mg/L). However, the fluoride concentrations detected in MW36-006 may not accurately reflect shallow groundwater conditions at this location because of the well's very shallow well screen (from 3 to 6 feet bgs).The high concentrations observed at MW36-006 are likely due to historical deposition associated with wastewater settling in this area. MW36-006 was decommissioned in June 1998.

Upper Gray Sand. Fluoride concentrations above the MCL in the UGS occur predominantly north of the dike and in localized areas north of scrap yard and east potliner in the southern portion of the site (see Figure 4-2).

- **North Landfill:** The elevated fluoride concentration at MW09-030 (31.5 mg/L) accounts for the localized UGS plume at north landfill. Surrounding monitoring well fluoride data range from 4 to 15 mg/L.
- **Company Lake:** Fluoride data collected at Geoprobe locations along the north side of Company Lake and at MW27-045 indicate elevated fluoride concentrations ranging from 15.9 to 24.5 mg/L in this area.

- **East Potliner and Scrap Yard:** August 1998 fluoride concentration monitoring well data for MW35-038 (< 0.40 mg/L) indicate a separation of the plumes situated around east potliner and scrap yard, in contrast to the August 1997 data, which suggested these two plumes were connected.

- **South Landfill:** The elevated fluoride concentration at GP59 (61 mg/L) accounts for a localized plume centered around south landfill. Surrounding Geoprobe fluoride concentrations in the area show low levels of fluoride and therefore a limited areal extent of the plume.

General Observations—UGS.

- **River Boundary:** The groundwater fluoride concentrations in the river Geoprobes and monitoring wells suggest that fluoride is discharging from the UGS, at concentrations above 4 mg/L, into the Columbia River at Geoprobe locations GP03 and GP04 and into the Sandy River at GP11. The fluoride detected in groundwater at GP11 is most likely from Company Lake. There is evidence from historical aerial photographs of an old Sandy River channel trending east-west through this area. This old channel may act as a preferential pathway for groundwater movement. The interpretation presented in Figure 4-2 assumes that a connection exists between the fluoride detected at GP11 and the fluoride present to the west near Company Lake. MW52-045 and MW53-034 were installed along the river to monitor future fluoride concentrations at these locations.

- **Bakehouse:** Sampling results indicate a localized area of fluoride exists in the UGS at the bakehouse. There is an apparent lateral displacement in the location of the highest fluoride concentration between the silt (Figure 4-1) and the UGS (Figure 4-2). The fluoride concentration in the silt was highest in MW46-018 at the southwest corner of the bakehouse. In the underlying UGS, the highest fluoride concentration was detected in MW42-027, located on the east side of the bakehouse. This displacement may only be apparent because silt well MW42-013 was either dry or purged dry during the August 1997 and 1998 sampling events; therefore, no fluoride information could be obtained.

- **Scrap Yard:** The fluoride concentrations of 66 mg/L in the UGS and 41.2 mg/L in the intermediate-depth sand at Geoprobe GP47, suggest a hydraulic connection between the silt and the underlying sand. This data suggest a possible connection between a scrap yard source area and fluoride concentrations at greater depths to the north (MW33-095 and MW33-165).

- **South Landfill:** Sampling results from Geoprobe GP49 indicate that fluoride is present in concentrations just above the field fluoride detection limit (0.4 mg/L) in the UGS. The presence of significant concentrations of fluoride (up to 414 mg/L) in the overlying silt suggests that the fluoride loading rate from the silt to the UGS in south landfill is very low. This is discussed in further detail in Section 5.2.

- **East Potliner:** Fluoride does not appear to have migrated very far toward the Sandy River from east potliner.

Intermediate-Depth Sand. The fluoride plume appears to extend from scrap yard to Company Lake and north to the Columbia River (see Figure 4-3).

- **Scrap Yard:** The fluoride distribution suggests a connection between scrap yard (GP47) and fluoride concentrations detected in MW33-095.
- **North of the Dike:** Based on the fluoride data from MW27-081 (22.3 mg/L in August 1998), the depicted fluoride plume concentration in this area was reduced from the 26 to 45 mg/L range to the 16 to 25 mg/L range.

General Observations—Intermediate-depth Sand.

- **River Boundary:** The fluoride concentrations from the Geoprobes suggest that fluoride is likely discharging from the intermediate-depth sand, at concentrations between 4 and 15 mg/L, into the Columbia River at Geoprobe location GP03.
- **Company Lake:** The Geoprobe locations along the north side of Company Lake were advanced to a target depth of 42 feet bgs; therefore, fluoride concentration data are not available for the intermediate-depth sand in this area, which occurs from approximately 62 to 100 feet bgs. The 4 to 15 mg/L contour interval (blue-shaded area) has been extended north of the lake because the magnitude of the concentrations in the overlying UGS suggest that fluoride is likely to be present at or above 4 mg/L in the intermediate-depth sand. Results also indicate that fluoride is present in the intermediate-depth sand on the south side of Company Lake (see Figure 4-3) and that concentrations are much lower in the overlying UGS in the same area (see Figure 4-2).
- **Western Boundary:** Low fluoride concentrations (2.0 mg/L or less) at GP32 through GP35 and at monitoring well MW39-095 (< 0.4 mg/L) indicate the proximity of the western extent of the fluoride plume.

Deep Sand/Gravel. The distribution of fluoride in the deep sand/gravel unit is limited to an area north of the central portion of the plant. The presence of the elevated fluoride concentration at MW33-165 (22.4 mg/L in August 1998) likely results from historical production well operation.

4.2.1.2 Vertical Distribution of Fluoride in Groundwater

Sitewide. Cross sections showing the vertical distribution of fluoride concentrations in groundwater across the site were constructed using field fluoride data from samples collected during 1996 Phase I monitoring well drilling, Geoprobe field fluoride data collected during summer 1997, and field fluoride data from the August 1997 groundwater sampling event. Sitewide cross section locations are shown in Figure 4-5. Field fluoride data collected during the 1998 Geoprobe field event focused on three soil and debris areas (south landfill, scrap yard, and east potliner). The use of the data collected over this time interval to construct fluoride distribution maps is considered a viable approach due to the small variations seen in fluoride concentrations over time.

West-Southwest Cross Section 1-1'. Figure 4-6, extending from Fairview Farms across Sundial Road to the scrap yard, shows the following:

- Fluoride concentrations exceeding the MCL (ranging from approximately 5 mg/L to 24 mg/L) are observed in groundwater in the intermediate-depth sand in the northwest portion of the site (MW31, MW06, and GP45) and extend eastward across the north central portion of the site (MW29 and GP24) into the deep sand/gravel.

- The fluoride concentration of 66 mg/L in the UGS at GP47 and the presence of fluoride at greater depths suggest a hydraulic connection between the silt and underlying sands as well as a possible connection between a scrap yard source area and fluoride concentrations at greater depths to the north (MW33). The interpretation of the fluoride distribution shown in MW33 and in GP47 (Figure 4-3) assumes a connection between scrap yard (GP47) and fluoride concentrations detected in MW33. This apparent downward migration may result from historical pumping of onsite production wells. The horizontal concentration contour maps for the UGS and intermediate-depth sand also support this interpretation of fluoride distribution (Figures 4-2 and 4-3).

Northwest-Southeast Cross Section 2-2´. Cross section 2-2´ (Figure 4-7) extends from the Columbia River near GP02, crosses Company Lake, the COE flood control dike, the main plant, and terminates at background monitoring well group MW03. Figure 4-7 shows that:

- The fluoride distribution appears asymmetrical, with respect to depth, in the vicinity of Company Lake. This distribution is likely the result of onsite production well pumping. Fluoride concentrations higher than the MCL (depicted by the 4 to 15 mg/L contour interval) are present in the UGS beneath and downgradient of the treatment pond. On the south side of the pond, fluoride concentrations above the MCL are not present in the UGS but are encountered at greater depth in the intermediate-depth sand. This interpretation of vertical distribution correlates with the horizontal fluoride concentration contours shown in Figures 4-2 and 4-3.
- There appears to be a downward trend in the fluoride distribution to the southeast of the pond in the direction of the plant. Fluoride concentrations above the MCL are encountered in the intermediate-depth sand at MW29 and in the deep sand/gravel at GP24. This distribution is likely the result of onsite production well pumping; that is, shallow fluoride in the vicinity of the pond is being pulled back towards the plant. This transport of fluoride is discussed in further detail in Section 5.1.
- Elevated fluoride concentrations associated with south landfill are depicted by the near surface fluoride plume to the southeast.

Soil and Debris Area Specific. Cross sections showing the vertical distribution of fluoride in soil and groundwater at soil and debris areas were constructed using August 1997 groundwater sampling event and 1998 Geoprobe field fluoride data. Cross section locations for scrap yard, east potliner, and south landfill are shown in Figure 4-8. Figures 4-9 through 4-14 depict the fluoride distribution in groundwater; Figures 4-15 through 4-20 show the fluoride distribution in soil. The cross sections suggest that only portions of the soil and debris areas are contributing fluoride to groundwater. General observations for each of the cross sections are provided below. A more detailed discussion of Figures 4-9 through 4-20 is presented in Section 5.2.2.1 in the context of fluoride transport, as well as in Appendix B of this report (Volume 3).

South Landfill.

Groundwater (Figures 4-9 and 4-10)

- The highest groundwater fluoride concentrations range between 200 and 1030 mg/L in the silt 15 to 20 feet bgs, rather than in the overlying sand, possibly indicating that the most concentrated material leached from the waste some time in the past.
- The fluoride in the groundwater in the UGS appears to be localized with a maximum detected concentration of 61 mg/L at Geoprobe GP59.

Soil (Figures 4-15 and 4-16)

- The highest soil fluoride concentrations were found in the waste material, ranging from 9,000 to 48,000 mg/kg. Concentrations in the overlying sand were considerably lower, generally ranging from 350 to 700 mg/kg, with one sample directly below the landfilled material containing 4,100 mg/kg fluoride.
- Soil fluoride concentrations in the silt were somewhat higher than in the overlying sand (ranging from 190 to 3,300 mg/kg).
- Unlike groundwater concentrations, soil fluoride concentrations tend to decrease with depth. This may indicate that groundwater concentrations in the silt reflect historical leaching of fluoride from materials with higher solubility limits than in the material leaching more recently. It may also be that, historically, more fluoride was available to leaching than now (that is, the leachable fluoride on the outside of the waste material has now been removed).
- Fluoride concentrations beneath the southeast portion of the landfill are considerably lower than those near the center or northwest portion (see Figure 4-16).

East Potliner.

Groundwater (Figure 4-11)

- Due to a lack of groundwater data, the horizontal extent of fluoride southeast of east potliner cannot be determined. However, the corresponding soil fluoride cross section shows fluoride concentrations up to 1,900 mg/kg (30 feet bgs) at GP67, suggesting groundwater concentrations may be elevated as well.
- The reduction of fluoride concentration at the bottom of Geoprobes GP65 and GP66 suggests the vertical extent of fluoride beneath east potliner is limited to the upper portion of the UGS and depths of approximately 60 feet bgs.

Soil (Figure 4-17)

- Soil concentrations near the existing ground surface were relatively low—approaching background in some areas. These samples were collected in the overlying sand, which was directly below the waste material removed during a time-critical-action in 1995-1996. The low fluoride concentrations suggest that an improvement has occurred as a result of the removal action.
- Elevated concentrations were detected in samples collected in the silt, with concentrations ranging from 380 to 2,700 mg/kg.

- Soil samples collected from the UGS had generally low concentrations of fluoride, with the exception of samples collected from GP66, which had concentrations of 2,700 mg/kg at the contact between the silt and the UGS, dropping to 700 mg/kg approximately 10 feet further into the UGS.

Scrap Yard.

Groundwater (Figures 4-12 through 4-14)

- Elevated fluoride concentrations appear to be limited to the northern portion of scrap yard. The fluoride plume beneath the northern portion of scrap yard appears to extend to a depth greater than 80 feet and to depths greater than 165 feet north of scrap yard (see MW33-165). The fluoride appears at shallower depths (25 feet or less) and at lower concentrations in the southern portion of scrap yard.
- The groundwater fluoride data from GP56 strongly suggest that the shallow fluoride at the northern portion of scrap yard is contributing to the fluoride detected in monitoring wells MW33-095 and MW33-165. Plant production well pumping is the likely hydraulic influence causing the downward fluoride movement and creating the fluoride distribution shown in Figure 4-13.
- The highest concentrations of fluoride may have leached from scrap yard historically. This is suggested by the measurement of higher concentrations downgradient of scrap yard as opposed to beneath scrap yard (see Figures 4-13 and 4-14).
- Figure 4-14 shows the depth relationships between shallow fluoride at scrap yard, screened intervals of monitoring wells north of scrap yard, and the screened intervals of the production wells farther to the north.

Soil (Figures 4-18, 4-19, and 4-20)

- The highest fluoride concentrations in soil samples were found just below the surface of scrap yard, ranging from 12,000 to 13,000 mg/kg at depths from near surface to 5 feet bgs.
- Concentrations decrease rapidly with depth, with the highest concentrations near the center of scrap yard (GP50/SB11). Concentrations in the overlying sands ranged from 190 to 13,000 mg/kg.
- Soil samples collected in the sandy silt and the UGS were relatively low in fluoride concentration, ranging from 210 to 590 mg/kg.
- Similar to the groundwater findings, elevated fluoride concentrations in soil appear to be limited to the northern portion of scrap yard, as shown in Figure 4-19. The soil fluoride concentrations beneath the southern portion of scrap yard range from 180 to 510 mg/kg, reflecting a different history of use of the north and south areas.

4.2.1.3 Potential Source Areas

Based on the horizontal and vertical distribution of fluoride, the following conclusions can be drawn.

- Company Lake appears to be a source of fluoride to groundwater. The presence of elevated fluoride concentrations in the intermediate-depth and deep sand/gravel south of Company Lake is likely due to the influence of onsite production well pumping rather than the migration of fluoride from soil and debris areas farther south (see Figures 4-3, 4-4, and 4-7).
- Figures 4-1 through 4-4 show other areas where fluoride concentrations exceed 4 mg/L: north landfill, east potliner, scrap yard, and south landfill.
- Fluoride concentrations above the MCL also occur at monitoring wells MW04-019 (located in the Building 97 subarea of the south wetlands) and MW36-006 (located adjacent to the south ditch). Elevated fluoride concentrations at these wells are likely due to historical deposition associated with wastewater settling in this area.
- Scrap yard appears to be the source of fluoride in the intermediate-depth sand and deep sand/gravel lying between the scrap yard and production wells (see Figures 4-3, 4-4, 4-6, and 4-13). Elevated levels of fluoride in the silt and UGS at south landfill and east potliner (see Figures 4-3 and 4-4) do not appear to contribute to this plume.
- At south landfill, silt and UGS contain elevated concentrations of fluoride. However, detections above the MCL in the UGS are only in a very localized area (at Geoprobe GP59). Other south landfill Geoprobe fluoride concentrations are below concentrations observed elsewhere in the UGS (that is, lower than at scrap yard and east potliner). The absence of fluoride in the intermediate-depth sands at and downgradient of south landfill is consistent with this observation.
- Fluoride movement in the silt unit appears to be vertically downward rather than horizontal. This observation is suggested by the limited extent of fluoride in the silt unit compared with the underlying units (see Figure 4-1 compared to Figures 4-2 and 4-3).

4.2.2 Metals

Six metals (antimony, arsenic, beryllium, chromium, lead, and nickel) were detected above MCLs at the RMC site between 1994 and 1997. In 1998, only arsenic and beryllium were detected in exceedance of the MCL (see Figure 4-21). Arsenic only exceeded the MCL in the silt unit at east potliner. Beryllium exceeded the MCL in the silt unit at east potliner and scrap yard. Metals exceeding MCLs over time at currently monitored well locations are summarized in Table 4-4 by area, well location, and year.

4.2.3 Cyanide

Cyanide is generated during aluminum reduction and can be found in spent potliner, used anodes, and other waste streams produced by the plant. Between 1994 and 1997, amenable cyanide was detected above the MCL at nine well locations: MW01-019 (cryolite ponds), MW11-017 (east potliner), MW19-013 and MW26-012 (south landfill), MW02-024 and MW13-022 (scrap yard) and MW33-165 (located northwest of scrap yard), MW04-019 (Building 97 subarea), and MW12-184 (western extent). In 1997, amenable cyanide was detected above the MCL (0.2 mg/L) at only one well location—MW33-165 (0.337 mg/L on 11/6/97). Amenable cyanide analysis was not included in the 1998 groundwater monitoring program but will be reevaluated during the 1999 monitoring program. Table 4-4 shows total cyanide in exceedance of the amenable cyanide MCL of 0.20 mg/L at currently monitored wells. As the information in Table 4-4 suggests, distribution of cyanide is limited to the silt unit and UGS at east potliner; the silt unit, intermediate and deep sands at scrap yard; and the silt unit only at south landfill.

4.2.4 VOCs

Toluene was detected in some deep monitoring wells during August and November 1996 (at concentrations well below the MCL of 1 mg/L), and volatile organic compounds (VOCs) were periodically detected at MW21-012. As a result, all monitoring wells at the site were sampled for VOCs in February 1997. Groundwater samples for VOC analysis were then collected in August 1997 at all wells in which VOCs were detected in February 1997. Based on the results of this effort and prior sampling events, 1998 groundwater sampling for VOC analysis was limited to wells where VOCs (other than toluene) were detected or exceeded MCLs in 1996 and 1997.

Analyses indicate that the occurrence of VOCs in exceedance of MCLs is limited to two shallow wells (MW32-040 and MW41-033) located near the northwest corner of the bakehouse (see Figure 4-22). The presence of 1,1-dichloroethene (1,1-DCE) and tetrachloroethene (PCE) above MCLs is probably attributable to historic plant operations. There is no indication that VOCs are migrating in the shallow portion of the aquifer. VOC exceedances of MCLs by well location and year are summarized in Tables 4-4 and 4-5.

4.2.5 Concentrations of Constituents of Potential Concern Over Time

Time-concentration trends for fluoride, metals, cyanide, and VOCs are discussed at length (by unit and by source area) in the *1998 Annual Groundwater Monitoring Report*. Historical fluoride and metals concentration data from 1994 through 1998 are provided in Tables B-1 and B-2 of Appendix B of the *1998 Annual Groundwater Monitoring Report*. General observations regarding constituent trends are presented below by area.

East Potliner.
Silt unit

- Fluoride concentrations in the groundwater within the silt unit appear to fluctuate over time and generally correlate with groundwater elevation changes. Lower groundwater levels generally correspond to lower fluoride concentrations (August 1995, 1996, and 1997) and higher groundwater levels correspond to higher fluoride concentrations (February 1996 and 1997). (See Figure 4-23.)
- Total arsenic concentrations in the groundwater within the silt unit appear to be declining toward the MCL (0.05 mg/L) in August 1998. Dissolved arsenic concentrations for February and August 1998 also exceeded the MCL. Lead concentrations (MCL = 0.015 mg/L) show a declining trend below the MCL to 0.006 mg/L in August 1998. (See Figure 4-24.)

UGS

- Figure 4-25 shows the fluoride concentration at UGS well MW35-038 declining from values above the MCL in 1997 to below detection limit values in 1998.

Intermediate-depth sand and deep sand/gravel

- There are no intermediate-depth or deep wells installed in east potliner.

Scrap Yard.
Silt unit

- Figure 4-26 shows that fluoride concentrations in the silt unit generally appear higher during the dry season (August 1995, 1996, 1997, and 1998) and lower during the wet season (February 1997 and 1998). This trend is opposite to the trend observed at east potliner.

Intermediate-depth sand and deep sand/gravel

- Monitoring wells MW33-095 and MW33-165, located north of scrap yard, continue to have the highest fluoride concentrations of the intermediate-depth and deep wells. After the historical high (141 mg/L) was measured at MW33-095 in February 1998, a decline in fluoride concentration (87 mg/L) occurred in August 1998 (see Figure 4-27). Deep well MW33-165 exhibits a similar pattern (see Figure 4-28). The decrease in fluoride concentrations appears to be the result of a change in production well operation. Fluctuations in fluoride concentrations at MW33-095 and MW33-165 are likely related to site production well operations.

South Landfill.
Silt unit

- Figure 4-29 shows fluoride concentrations in the silt unit appear to have stabilized over time (70 mg/L at MW19-013 since August 1997 and approximately 100 mg/L at MW26-012 since February 1997).
- Beryllium concentrations (0.0053 mg/L in August 1997 and 0.0046 mg/L in August 1998) appear to be declining toward the MCL of 0.004 mg/L (see Figure 4-30).

Bakehouse.
A series of silt unit and UGS wells were installed around the perimeter of the bakehouse in June 1997. Based on a limited data set, fluoride concentrations in the bakehouse appear variable.

Silt unit

- In the shallow silt unit, MW46 exhibits the highest fluoride concentrations (up to 28 mg/L) near the bakehouse; however, concentrations have declined over time (to approximately 19 mg/L). At MW45, fluoride concentrations appear to be fairly consistent (ranging between 9 and 13 mg/L), while fluoride concentrations at MW41 appear to be stable below the MCL (see Figure 4-31).

UGS

- Figure 4-32 shows fluoride MCL exceedances for shallow UGS wells. Data indicate an upward trend at MW42-027, a declining trend at MW44-027, and fairly consistent concentrations at MW43-027.

- Tetrachloroethene (PCE) was detected above the MCL of 0.005 mg/L at MW32-040, located near the northwest corner of the bakehouse. The average PCE concentration in the UGS during 1997 was 0.32 mg/L. During 1998, it was 0.35 mg/L.

Intermediate-depth sand

- There are no intermediate-depth wells in the immediate vicinity of the bakehouse.

Deep sand/gravel

- Deep wells MW48-165 and MW29-179, located northwest of the bakehouse, show increasing fluoride concentration trends (see Figure 4-28).

North Landfill.

UGS

Fluoride concentrations in the UGS at MW 09-030 appear to fluctuate over time (between 13 and 32 mg/L). A close correlation between fluoride concentration and groundwater level is not apparent. Fluoride concentrations at MW22-027 (approximately 14 mg/L) and MW27-045 (approximately 20 mg/L) appear to have stabilized between August 1997 and August 1998 (see Figure 4-33).

Company Lake.

Intermediate-depth sand

Fluoride concentrations in intermediate-depth wells appear to be increasing at MW27-081, then leveling off in 1998 to approximately 21 mg/L; staying fairly consistent (ranging from nine to 15 mg/L) at MW29-090; and fluctuating over time at Fairview Farms well MW31-095 (see Figure 4-27).

Table 4-1
Troutdale Facility Wastes
Reynolds Metals Company – Troutdale, Oregon

Waste	Description	Quantity Generated per Year	Disposition
Carbon Plant and Bakehouse			
Coal tar pitch sludge	Sludge generated from electrostatic precipitators (ESPs) attached to the carbon bake when NaOH is injected into the scrubbing liquor for pH control (counter SO_2). Contains polycyclic aromatic hydrocarbons (PAHs).	1,200 tons	**EPA (1980b)** reported that this waste was sent to Chem-Nuclear (now Chemical Waste Management) in Arlington, Oregon. **DEQ (1984)** reported that this waste was totally and directly reused in the baking furnaces. **DEQ (1985)** found that the sludge is not a state hazardous waste. Currently sent to industrial waste landfill in Hillsboro, Oregon.
ESP solids	Solids precipitated with CaCl from ESP bleed water. Solids are pressed out in filter press. Effluent is discharged to ditch behind plant.	300 to 400 tons	Currently disposed of at industrial waste landfill, Hillsboro, Oregon.
Butt screening	Ground remains of carbon anodes that are not usable after use in pots.	500 to 600 tons	Currently disposed of at industrial waste landfill, Hillsboro, Oregon. Most wastes reused in making new anodes.
"Lectromelt" solids	Slaglike material removed from furnaces in the rodding room during production of cast iron rods.	50 tons	Currently disposed of at industrial waste landfill, Hillsboro, Oregon. Most wastes reused in making new anodes.
Rodding room baghouse dust	Collected from around Lectromelt furnaces during production of cast iron.	20 to 25 tons	Currently disposed of at industrial waste landfill, Hillsboro, Oregon. Most wastes reused in making new anodes.
Furnace brick	Generated from brick-lined carbon baking furnaces.	3,000 tons	Disposed of onsite; mostly used for riprap and dike stabilization.

Table 4-1
Troutdale Facility Wastes
Reynolds Metals Company – Troutdale, Oregon

Waste	Description	Quantity Generated per Year	Disposition
Casthouse			
Spent charcoal	Used as a filtering material for removal of various electrolytic bath components and other impurities from molten aluminum.	700 to 900 tons	Currently disposed of at industrial waste landfill, Hillsboro, Oregon, or Finley Buttes landfill, Boardman, Oregon.
Baghouse dust	Generated from holding furnaces that are fluxed with chloride and nitrogen gas.	20 tons	**EPA (1980b)** reported this dust was sent to Obrist landfill. Currently is sent to industrial waste landfill, Hillsboro, Oregon.
Trough refractory	Material that lines the troughs that carry molten aluminum from holding furnaces to the casthouse.	Variable	Currently is sent to Hillsboro, Oregon; up to 1992, a portion was dumped with refractory brick on the onsite dike.
Wastewater Treatment Plant			
Filter press liquor	Generated from dewatering of waste treatment sludge.	Variable	Flows into effluent stream, which is regulated by NPDES permit for wastewater treatment plant.
Sewage sludge	Dewatered sludge from plant.	1 to 2 tons	Onsite application; RMC says DEQ allows this if spread no more than 2 inches thick.
Pot Rooms			
Spent potliner	Carbon cathode material removed from reduction cells at end of lifetime.	4,600 tons	Currently sent to Chemical Waste Management landfill, Arlington, Oregon.

Table 4-1
Troutdale Facility Wastes
Reynolds Metals Company – Troutdale, Oregon

Waste	Description	Quantity Generated per Year	Disposition
Other Facility Operations and Maintenance			
Corrugated steel siding	Asphalt-type coating containing polychlorinated biphenyls PCBs).	Variable	Currently sent to hazardous waste landfill, Arlington, Oregon.
Laboratory solvents	Includes toluene, xylene, kerosene, and quinoline.	10 gallons	**DEQ (1984)** reported these wastes were sent to hazardous waste landfill, Arlington, Oregon. Currently, they are sent to incinerator, Sauget, Illinois.
Paint solvents and pigments	Generated from cleaning paint buckets, cans, and brushes during maintenance.	Variable	Currently sent to incinerator, Sauget, Illinois. Sometime in 1993, sent to Systec, Fredonia, Kansas, as alternative fuel for cement kiln. Empty cans are sent to industrial waste landfill, Hillsboro, Oregon.
Steam cleaner solids	Generated from routine cleaning of plant equipment.	5 tons	Currently sent to hazardous waste landfill, Arlington, Oregon.
Sandblast waste	Generated from cleaning of various types of equipment, including pot shells.	Variable	Currently sent to hazardous waste landfill, Arlington, Oregon.
Used oil	Oil drained from equipment of various types (non-PCB).	3,000 to 3,500 gallons	Reprocessed by Harbor Oil and used as fuel (not at RMC plant).
PCB waste	Oil and solids from maintenance of transformers and capacitors.	Variable	≥50 parts per million of oil incinerated at Sauget, Illinois, or Port Arthur, Texas. <50 parts per million of oil used as alternative fuel. Solids currently sent to hazardous waste landfill, Arlington, Oregon.
Petroleum naphtha	Generated from cleaning of parts.	3 to 5 tons	Serviced by Safety Kleen Corporation (recycled).
Asbestos waste	Miscellaneous construction debris.	100 to 150 pounds	Currently sent to industrial waste landfill, Hillsboro, Oregon.

Table 4-2
Summary of Groundwater Source Areas at the RMC Site
Reynolds Metals Company - Troutdale, Oregon

Source Area	Source Type	Disposal Period	Waste Description	Detected Constituents in Groundwater
Soil and Debris Areas				
North Landfill	Landfill	Active from 1968 to 1985	Refractory brick, black carbonlike material, miscellaneous debris	Metals, cyanide, fluoride, VOCs
South Landfill	Landfill	Active from 1940s to early 1970s	Refractory brick, black carbonlike material, miscellaneous debris	Metals, cyanide, fluoride, VOCs
Scrap Yard	Surface release/landfill	Early 1940s to present	Brick fill, debris, manufacturing by-products	Metals, cyanide, fluoride, VOCs
South Wetlands (includes Building 97 subarea)	Direct discharge, surface release/spill	Used as settling basin from early 1940s to 1965	Process residue from air emission, liquid spills from wet scrubber system liquid treatment systems	Metals, cyanide, fluoride
Fairview Farms	Surface release	Since early 1940s	Airborne deposition, dredge spoils, debris piles	Metals, fluoride, cyanide
East Potliner Area	Surface release	Early 1940s to 1975	Material resembling potliner, metallic waste	Cyanide, fluoride, metals
Cryolite Ponds	Direct discharge	1965 to 1977	Storage and recovery of air emission control process residue, reused for cryolite production	Metals, cyanide, fluoride
Bakehouse Sumps	Surface release	Early 1940s to present	Condensate from drains from wet electrostatic precipitators, intermittent wastewater discharges, stormwater flow	Metals, cyanide, fluoride, PAHs, VOCs
Wastewater Discharge Area				
Company Lake	Direct discharge	Late 1940s to present	Process wastewater, solids, refractory brick, and stormwater discharges via South Ditch	Metals, cyanide, fluoride, VOCs
South Ditch	Direct discharge	Early 1940s to present	Process wastewater	Metals, cyanide, fluoride, PAHs, VOCs

Notes:
PAHs = polynuclear aromatic hydrocarbons
VOCs = volatile organic compounds

Table 4-3
Groundwater Monitoring Well MCL Exceedances for 1997 and 1998
Reynolds Metals Company - Troutdale, Oregon

				Primary MCL Exceedances *(mg/L)*											
				VOCs		Arsenic		Beryllium		Chromium	Cyanide	Fluoride		Lead	Nickel
Well	Area Monitored	Hydrogeologic Unit	Date Sampled	1,1-DCE 0.007	PCE 0.005	Total 0.05	Dissolved 0.05	Total 0.004	Dissolved 0.004	Total 0.10	Amenable 0.2	by 300.0 4.0	by Field 4.0	Total 0.015	Total = 0.1
MW01-019	Cryolite Ponds/	Silt	2/19/97									30.7			
	South Ditch		8/21/97										22		
MW02-012	Scrap Yard	Silt	2/24/97									30.3			
			8/20/97										16		
MW02-034	Scrap Yard	UGS	2/24/97									6.69			
			8/22/97										6		
MW03-017	Background	Silt	2/17/97												
			5/16/97												
			8/22/97												
			11/7/97												
MW03-098	Background	Intermediate	2/17/97												
			5/16/97												
			8/22/97												
			11/7/97												
MW03-175	Background	Deep	2/17/97												
			5/16/97												
			8/22/97												
			11/7/97												
MW04-019	South Ditch	Silt	2/21/97									33.2			
			8/21/97					.0054				90.3	58		.135
MW05-025	Background	Silt	2/25/97												
			5/14/97												
			8/21/97												
			11/5/97												
			2/16/98												
			8/19/98												
MW06-094	Company Lake	Intermediate	2/20/97									13.4 J			
			5/13/97									13			
			8/20/97										16		
			11/5/97										15.9		
MW06-176	Company Lake	Deep	2/20/97												
MW07-024	Company Lake	Silt	5/15/97												
MW08-027	North Plant	UGS	2/17/97												
			5/12/97											.0175	
			8/18/97												
			11/3/97												
MW08-127	North Plant	Intermediate	2/17/97												
			5/12/97												
			8/18/97												
			11/3/97												
MW08-169	North Plant	Deep	1/7/97												
			2/17/97												
MW09-030	North Landfill	UGS	2/17/97									27.6			
			8/18/97										14		
			2/19/98										25.4		
			8/13/98										31.5		
MW10-023	East Plant	Silt	2/25/97												
			5/13/97												
			8/25/97												
			11/10/97												
			2/18/98												
			8/18/98												

Table 4-3
Groundwater Monitoring Well MCL Exceedances for 1997 and 1998
Reynolds Metals Company - Troutdale, Oregon

				Primary MCL Exceedances *(mg/L)*											
				VOCs		*Arsenic*		*Beryllium*		*Chromium*	*Cyanide*	*Fluoride*		*Lead*	*Nickel*
Well	**Area Monitored**	**Hydrogeologic Unit**	**Date Sampled**	**1,1-DCE 0.007**	**PCE 0.005**	**Total 0.05**	**Dissolved 0.05**	**Total 0.004**	**Dissolved 0.004**	**Total 0.10**	**Amenable 0.2**	**by 300.0 4.0**	**by Field 4.0**	**Total 0.015**	**Total = 0.1**
MW10-090	East Plant	Intermediate	2/25/97												
			5/13/97												
			8/20/97												
			11/10/97												
MW10-165	East Plant	Deep	2/25/97												
			5/13/97												
MW11-017	East Potliner	Silt	2/25/97			.114						522			
			8/21/97			.11						396	360	.0171	
			2/16/98			.092	.087					385	306		
			8/17/98			.08	.078					432	440		
MW12-021	Western Extent	Silt	2/21/97												
			5/15/97												
			8/20/97												
			11/6/97												
MW12-092	Western Extent	Intermediate	2/21/97												
			5/15/97												
			8/20/97												
			11/6/97												
MW12-184	Western Extent	Deep	2/21/97												
			5/15/97												
			11/6/97												
MW13-022	Scrap Yard	Silt	2/24/97									94			
			8/20/97									112	98		
			2/19/98									104	108		
			8/17/98					.0047	.0045			119	130		
MW14-015	Scrap Yard	Silt	2/21/97									6.03			
			8/20/97									5.92	9.1		
MW15-024	Western Extent	Silt	2/21/97												
			5/15/97												
			8/25/97												
			11/10/97												
MW15-086	Western Extent	Intermediate	2/21/97												
			5/15/97												
			8/25/97												
			11/10/97												
MW15-175	Western Extent	Deep	2/21/97												
			5/15/97												
			8/25/97												
			11/10/97												
MW16-014	South Ditch	Silt	2/18/97									22.9			
			5/16/97									9.9			
			8/22/97										10.1		
MW17-016	South Wetlands	Silt	2/18/97												
MW17-028	South Wetlands	Silt	2/18/97												
			8/22/97												
			2/19/98												
MW18-016	South Wetlands	Silt	2/18/97									7.54			
			8/22/97									7.1	7.2		
MW18-031	South Wetlands	UGS	2/18/97												
			8/22/97												
MW19-013	South Landfill	Silt	2/19/97									50.3			
			8/22/97					.0053					67		
			8/19/98					.0046					66.3		

Table 4-3
Groundwater Monitoring Well MCL Exceedances for 1997 and 1998
Reynolds Metals Company - Troutdale, Oregon

				Primary MCL Exceedances *(mg/L)*											
				VOCs		Arsenic		Beryllium		Chromium	Cyanide	Fluoride		Lead	Nickel
Well	Area Monitored	Hydrogeologic Unit	Date Sampled	1,1-DCE 0.007	PCE 0.005	Total 0.05	Dissolved 0.05	Total 0.004	Dissolved 0.004	Total 0.10	Amenable 0.2	by 300.0 4.0	by Field 4.0	Total 0.015	Total =0.1
MW20-026	Company Lake	UGS	2/18/97												
			5/12/97												
			8/19/97										5		
			11/4/97										6.1		
MW21-012	North Landfill	Silt	2/18/97					.0244				57.2			
			8/18/97					.0137				38.3	36.6		
MW21-025	North Landfill	UGS	2/18/97									12.6			
			5/12/97									11.4			
			8/18/97										12.1		
			11/4/97										10.1		
MW21-063	North Landfill	Intermediate	2/18/97												
			5/12/97												
			8/18/97												
			11/4/97												
MW21-176	North Landfill	Deep	2/18/97												
MW22-027	Company Lake	UGS	2/19/97									20.1			
			5/12/97									16.2			
			8/19/97										22		
			11/4/97										14.4		
			2/19/98										14		
			8/20/98										13.6		
MW23-025	North Landfill	UGS	2/19/97									18.2			
			8/18/97										9.1		
MW24-010	Scrap Yard	Silt	2/24/97									15.9			
			8/20/97										6.5		
MW25-024	Scrap Yard	Silt	2/20/97									26.6 J			
			8/20/97									21.1	24		
MW25-035	Scrap Yard	UGS	2/20/97												
			8/22/97												
MW26-012	South Landfill	Silt	2/19/97									99.5			
			8/21/97									104	90		.113
			2/16/98									101	87		
			8/17/98									99.5	94		
MW27-045	Company Lake	UGS	2/19/97												
			5/13/97									18.6			
			8/19/97										23		
			11/4/97										20.5		
			2/19/98										19.4		
			8/18/98										20.2		
MW27-081	Company Lake	Intermediate	2/19/97									19.5			
			5/13/97									19.5			
			8/18/97									19	26		
			11/4/97										22.3		
			2/19/98										22.1		
			8/18/98										22.3		
MW27-176	Company Lake	Deep	2/19/97												
MW28-160	Bakehouse	Deep	2/19/97												
			5/19/97												
			8/20/97												
MW29-033	Company Lake	UGS	2/20/97												
			5/14/97												
			8/19/97												
			11/5/97												

Table 4-3
Groundwater Monitoring Well MCL Exceedances for 1997 and 1998
Reynolds Metals Company - Troutdale, Oregon

				Primary MCL Exceedances (mg/L)											
				VOCs		Arsenic		Beryllium		Chromium	Cyanide	Fluoride		Lead	Nickel
Well	Area Monitored	Hydrogeologic Unit	Date Sampled	1,1-DCE 0.007	PCE 0.005	Total 0.05	Dissolved 0.05	Total 0.004	Dissolved 0.004	Total 0.10	Amenable 0.2	by 300.0 4.0	by Field 4.0	Total 0.015	Total = 0.1
MW29-090	Company Lake	Intermediate	2/20/97									13.9 J			
			5/14/97									13			
			8/19/97										9.2		
			11/5/97										13.2		
			2/17/98										12		
			8/11/98										15		
MW29-179	Company Lake	Deep	2/20/97												
			8/19/97												
			11/5/97												
			2/17/98												
			8/12/98												
MW30-100	Company Lake	Intermediate	2/24/97												
			5/14/97												
			8/21/97												
			11/5/97												
MW31-034	Company Lake/ Fairview Farms	UGS	2/21/97												
			5/13/97												
			8/25/97												
			11/5/97												
			2/20/98										4.97		
MW31-095	Company Lake/ Fairview Farms	Intermediate	2/21/97									20			
			5/13/97									20.1			
			8/25/97									21.2	24		
			11/5/97										25.4		
			2/20/98										6.58		
			8/13/98										20.9		
MW32-040	Plant Interior	UGS	2/25/97	.008	.29 D										
			5/15/97		.21 D										
			8/25/97		.4 D										
			2/17/98		.34 D										
			8/12/98		.37 D										
MW32-095	Plant Interior	Intermediate	2/25/97												
			5/14/97												
			8/25/97												
			11/6/97												
MW32-165	Plant Interior	Deep	2/25/97												
			5/14/97												
			8/25/97												
			11/6/97												
MW33-033	Plant Interior	UGS	2/25/97												
			5/16/97												
			8/25/97												
			11/6/97												
MW33-095	Plant Interior	Intermediate	2/25/97									56.8			
			5/16/97									56.2			
			8/25/97									82.5	80		
			11/6/97									112	105		
			2/17/98									113	141		
			8/11/98										87.4		

Table 4-3
Groundwater Monitoring Well MCL Exceedances for 1997 and 1998
Reynolds Metals Company - Troutdale, Oregon

				Primary MCL Exceedances (mg/L)											
				VOCs		Arsenic		Beryllium		Chromium	Cyanide	Fluoride		Lead	Nickel
Well	Area Monitored	Hydrogeologic Unit	Date Sampled	1,1-DCE 0.007	PCE 0.005	Total 0.05	Dissolved 0.05	Total 0.004	Dissolved 0.004	Total 0.10	Amenable 0.2	by 300.0 4.0	by Field 4.0	Total 0.015	Total = 0.1
MW33-165	Plant Interior	Deep	2/25/97									17.2			
			5/16/97									17.5			
			8/27/97										23		
			11/6/97								0.337		25		
			2/17/98										40.7		
			8/18/98										22.4		
MW34-038	East Potliner	UGS	2/24/97									29			
			5/20/97									30.4			
			8/27/97										28		
			11/6/97										33		
			2/16/98										28.4		
			8/18/98										35.4		
MW35-038	East Potliner	UGS	2/24/97									5.02			
			5/19/97												
			8/25/97										6		
			11/7/97												
MW36-006	South Wetlands	Silt	2/21/97									94.9 J			
			2/22/97					.0066							.185
			5/15/97					.0142		.112		96		.0363	
			8/28/97					.0154		.129		105		.042	.132
			11/4/97					.0102						.0254	.279
			11/6/97									120			
			11/7/97										62.9		
MW37-012	South Wetlands	Silt	2/20/97												
			5/20/97												
			8/25/97										5.1		
			11/10/97										5.4		
MW37-030	South Wetlands	UGS	2/20/97												
			5/20/97												
			8/25/97												
			11/10/97												
MW38-007	South Wetlands	Silt	8/21/97												
MW38-035	South Wetlands	UGS	2/19/97												
			5/15/97												
			8/21/97												
			11/7/97												
MW39-095	Fairview Farms	Intermediate	8/22/97												
			11/5/97												
MW40-018	Bakehouse	Silt	8/26/97												
			11/10/97												
			5/11/98										5.7		
			8/14/98										5.2		
MW40-030	Bakehouse	UGS	8/27/97												
MW41-020	Bakehouse	Silt	8/26/97												
			11/11/97												
MW41-033	Bakehouse	UGS	8/27/97		.006										
			11/11/97												
MW42-027	Bakehouse	UGS	8/27/97									16.1	13		
			11/10/97										14.4		
			2/18/98										16.8		
			5/11/98										17.2		
			8/12/98										22		

Table 4-3
Groundwater Monitoring Well MCL Exceedances for 1997 and 1998
Reynolds Metals Company - Troutdale, Oregon

				Primary MCL Exceedances (mg/L)											
				VOCs		Arsenic		Beryllium		Chromium	Cyanide	Fluoride		Lead	Nickel
Well	Area Monitored	Hydrogeologic Unit	Date Sampled	1,1-DCE 0.007	PCE 0.005	Total 0.05	Dissolved 0.05	Total 0.004	Dissolved 0.004	Total 0.10	Amenable 0.2	by 300.0 4.0	by Field 4.0	Total 0.015	Total = 0.1
MW43-015	Bakehouse	Silt	2/18/98										6.28		
			5/13/98										9.5		
MW43-027	Bakehouse	UGS	8/26/97									8.42	7.7		
			11/11/97										8.29		
			2/18/98										5.42		
			5/13/98										8.1		
			8/12/98										9.2		
MW44-027	Bakehouse	UGS	8/26/97									5.58	6.4		
			11/11/97										5		
			2/20/98										5.8		
MW45-017	Bakehouse	Silt	8/25/97									8.1	9.2		
			11/7/97										12.3		
			2/20/98										13.4		
			5/12/98										9.2		
			8/13/98										12.6		
MW45-042	Bakehouse	UGS	8/20/97												
			11/7/97												
MW46-018	Bakehouse	Silt	8/25/97									26.4	28		
			11/11/97										21.1		
			2/20/98										18.9		
			5/12/98										16.8		
			8/10/98										19.2		
MW46-043	Bakehouse	UGS	8/21/97												
			11/11/97												
MW47-094	Cryolite Ponds	Intermediate	8/21/97												
			11/11/97												
MW48-055	Plant Interior	Intermediate	11/19/97												
			11/19/97									6.81	7.02		
			2/18/98										7.4		
MW48-165	Plant Interior	Deep	8/11/98										8		
MW49-095	Scrap Yard	Intermediate	11/18/97												
MW49-145	Scrap Yard	Deep	11/18/97												
			2/17/98												
			8/17/98												
MW50-094	Plant Interior	Intermediate	11/19/97												
MW51-069	Columbia River	Intermediate	5/11/98												
			8/10/98												
MW52-045	Columbia River	UGS	11/10/97									9.26	8.9		
			2/19/98										10.8		
			5/11/98										6.11		
			8/10/98										10.3		
MW53-034	Sandy River	UGS	11/11/97												
			5/11/98												
			8/10/98												

Notes:
TDS = Total dissolved Solids
PCE = Tetrachloroethene
1,1-DCE = 1,1-Dichloroethene

Table 4-4
Cyanide, Metals, and VOC Concentrations in Groundwater at Currently Monitored Well Locations
Reynolds Metals Company - Troutdale, Oregon

Well ID	Unit	Date Sampled	VOC PCE MCL = 0.005	Arsenic Total (T) MCL = 0.05	Arsenic Dissolved (D) MCL = 0.05	Beryllium T MCL = 0.004	Beryllium D MCL= 0.004	Cyanide T MCL = 0.20	Lead T MCL = 0.015	Lead D MCL = 0.015	Nickel T MCL = 0.10	Nickel D MCL = 0.10
MW05-025		07/18/94		0.004 U		0.02 U		0.01 U	0.004 U		0.05 U	
	Silt	08/08/96		0.004 U		0.0003 U		0.02 U	0.001 U		0.04 U	
Background		11/21/96		0.0011 U		0.0003 U		0.061	0.0009 U		0.0073 U	
Well		02/25/97	0.001 U	0.004 U		0.0006		0.01 U	0.001 U		0.04 U	
		05/14/97		0.004 U		0.0003 U		0.02 U	0.001 U		0.04 U	
		08/21/97		0.004 U		0.00039		0.02 U	0.0019		0.04 U	
		11/05/97		0.004 U		0.0003 U		0.02 U	0.001 U		0.04 U	
		02/16/98		0.004 U		0.0003 U			0.001 U		0.04 U	
		08/19/98		0.004 U		0.0003 U			0.001 U		0.04 U	
MW11-017		08/15/94	0.0001 U	**0.16**	**0.083**	0.02 U	0.02 U	**0.72**	**0.10**	**0.056**	**0.55**	**0.22**
	Silt	11/07/94		**0.18**	**0.15**	0.02 U	0.02 U	**0.49**	**0.05**	0.01	**0.24**	0.07
		02/06/95		**0.16**	**0.14**	0.02 U	0.02 U	**0.51**	**0.03**	0.0048	**0.14**	0.05 U
EPL		02/23/95						**0.4**				
		05/11/95		**0.0993**	**0.0999**	0.0015	0.001	**0.562**	0.0083	0.005 U	0.0644	0.049
		08/07/95		**0.126**	**0.0956**	0.0018	0.00085	**0.46**	0.0104	0.005 U	0.0661	0.05
		12/04/95						**0.63**				
		02/13/96		**0.115**	**0.104**	0.0032	0.0012	**0.88**	**0.0207**	0.0026	**0.101**	0.045
		05/14/96						**0.74**				
		08/08/96		**0.121**	**0.119**	0.0034	0.0017	**0.47**	**0.0266**	0.0047	**0.104**	0.0568
		02/25/97	0.001 U	**0.114**		0.0025		**0.603**	0.0098		0.0683	
		08/21/97		**0.11**		0.0018		**0.674**	**0.0171**		0.096	
		02/16/98		**0.092**	**0.087**	0.00083	0.0003 U		0.0061	0.001	0.0425	0.04 U
		08/17/98		**0.08**	**0.078**	0.0017	0.0013		0.0058	0.0047	0.0506	0.0462
MW13-022		08/07/95		0.0111		0.0039		**2.5**	0.005 U		0.04 U	
	Silt	12/04/95		0.0075		**0.0063**		**0.86**	0.0012		0.04 U	
SY		02/09/96		0.0078		**0.0058**		**0.34**	0.001 U		0.04 U	
		05/13/96		0.0077		0.0039		0.09	0.0013		0.04 U	
		08/07/96		0.0206	0.01	0.0036	0.0038	**0.62**	0.0013	0.001 U	0.04 U	0.04 U
		02/24/97	0.001 U	0.0083		0.0035		0.06	0.0013		0.04 U	
		08/20/97		0.0094		0.0024		0.132	0.0015		0.04 U	
		02/19/98		0.0075	0.0067	0.0026	0.0025		0.001 U	0.001 U	0.04 U	0.04 U
		08/17/98		0.0093		0.0047	**0.0045**		0.001 U		0.04 U	0.04 U
MW19-013		08/09/95	0.001 U	0.004 U	0.004 U	**0.0043**	**0.0043**	0.042	0.005 U	0.005 U	0.04 U	0.04 U
	Silt	12/07/95		0.004 U		**0.0041**		0.17	0.001 U		0.04 U	
SY		02/09/96		0.004 U		**0.0059**		**0.44**	0.001 U		0.04 U	
		05/16/96		0.004 U		0.0039		0.02	0.001 U		0.04 U	
		08/08/96		0.004 U		**0.0054**		**0.56**	0.001 U		0.04 U	
		02/19/97	0.001 U	0.004 U		0.0028		0.028	0.001 U		0.04 U	
		08/22/97		0.004 U		**0.0053**		0.01	0.001 U		0.04 U	
		08/19/98		0.004 U		**0.0046**			0.001 U		0.04 U	
MW26-012		08/09/95	0.001 U	0.004 U	0.004 U	0.0024	0.0023	**0.74**	0.005 U	0.005 U	0.04 U	0.04 U
	Silt	12/07/95		0.004 U		0.0028		**0.42**	0.0014		0.04 U	
SLF		02/09/96		0.004 U		0.0029		**0.34**	0.001 U		0.04 U	
		05/16/96		0.004 U		0.0028		**0.36**	0.0014		0.04 U	
		08/08/96		0.004 U		0.003		0.02	0.0028		0.04 U	
		02/19/97	0.001 U	0.004 U		0.0032		**0.395**	0.001 U		0.04 U	
		08/21/97		0.004 U		0.0028		**0.548**	0.0016		**0.113**	

Table 4-4
Cyanide, Metals, and VOC Concentrations in Groundwater at Currently Monitored Well Locations
Reynolds Metals Company - Troutdale, Oregon

Well ID	Unit	Date Sampled	VOC PCE MCL = 0.005	Arsenic Total (T) MCL = 0.05	Arsenic Dissolved (D) MCL = 0.05	Beryllium T MCL = 0.004	Beryllium D MCL= 0.004	Cyanide T MCL = 0.20	Lead T MCL = 0.015	Lead D MCL = 0.015	Nickel T MCL = 0.10	Nickel D MCL = 0.10
MW32-040		02/25/97	**0.29 D**	0.004 U		0.0006		0.01 U	0.001 U		0.04 U	
	UGS	05/15/97	**0.21 D**	0.004 U		0.0003 U		0.02 U	0.001 U		0.04 U	
Plant		08/25/97	**0.4 D**	0.004 U		0.0003 U		0.02 U	0.0027		0.04 U	
Interior		11/06/97		0.004 U		0.0003 U		0.02 U	0.001 U		0.04 U	
		02/17/98	**0.34 D**									
		08/12/98	**0.37 D**									
MW33-033		02/25/97	0.001 U	0.0062		0.00062		0.01 U	0.001 U		0.04 U	
Plant	UGS	05/16/97	0.001 U	0.0059		0.0003 U		0.02 U	0.001 U		0.04 U	
Interior		08/25/97	0.001 U	0.0065		0.0003 U		0.02 U	0.001 U		0.04 U	
		11/06/97		0.0077		0.0003 U		0.02 U	0.001 U		0.04 U	
MW33-095		02/25/97	0.001 U	0.0096		0.0017		**0.379**	0.0084		0.04 U	
	I	05/16/97	0.001 U	0.0077		0.0013		**0.348**	0.0091		0.04 U	
Plant		08/25/97	0.001 U	0.0096		0.0021		**0.25**	0.005		0.04 U	
Interior		11/06/97		0.0095		0.003		**0.402**	0.0036		0.04 U	
		02/17/98	0.0002 J									
		08/11/98	0.001 U									
MW33-165		02/25/97	0.001 U	0.004 U		0.00061		**1.6**	0.0016		0.04 U	
Plant	Deep	05/16/97	0.001 U	0.004 U		0.00034		**0.872**	0.0011		0.04 U	
Interior		08/27/97	0.001 U	0.004 U		0.0006		**0.816**	0.001 U		0.04 U	
		11/06/97		0.004 U		0.00086		**1.17**	0.001 U		0.04 U	
MW34-038		02/24/97	0.001 U	0.004		0.00088		**1.11**	0.001 U		0.04 U	
	UGS	05/20/97		0.004 U		0.00072		**0.936**	0.0011		0.04 U	
EPL		08/27/97	0.001 U	0.004 U		0.0004		**0.932**	0.001 U		0.0719	
		11/06/97		0.004 U		0.00043		**0.944**	0.001 U		0.04 U	

Notes:

All analyte concentrations are in mg/L.

MCL exceedances are bolded.

Abbreviations:

PCE = tetrachloroethene.

J = estimated.

U = nondetect.

Table 4-5
1997 and 1998 VOC MCL Exceedances

	Date		1,1-Dichloroethene (mg/L)	Tetrachloroethene (mg/L)
Well ID	Sampled	Action Level	0.007	0.005
MW32-040	2/25/97		0.008	0.29D
	5/15/97			0.21D
	8/25/97			0.40D
	2/17/98			0.34D
	8/12/98			0.37D
MW41-033	8/27/97			0.006

D = diluted value

SECTION 5

Fluoride Migration in Groundwater

SECTION 5
Fluoride Migration in Groundwater

This section discusses the movement of fluoride in groundwater, with an emphasis on the hydraulic and chemical transport mechanisms that affect the presence of fluoride in groundwater beneath the RMC facility. As discussed in Section 4, fluoride is the primary constituent of potential concern at the RMC facility because it is the only constituent that is prevalent beneath the site at concentrations exceeding the MCL. Consequently, the fate and transport information in this section is limited to fluoride and does not address other chemical constituents that have been detected in site groundwater at low levels and in limited areas.

The migration of fluoride in the subsurface is governed, in part, by groundwater flow patterns. However, the concentration of fluoride in groundwater and its migration over time is also strongly controlled by its physical properties (such as its propensity to bind to the soils that form the aquifer matrix) and by the natural geochemistry of the groundwater system. Consequently, fluoride can potentially migrate at substantially different rates in different aquifer zones and can also undergo phase changes.[1]

Information in this section is organized as follows:

- **Section 5.1: Groundwater migration pathways.** Identifies groundwater flow patterns beneath soil and debris areas and in the portions of the aquifer that currently contain fluoride. Includes evaluations of whether there is a potential for hydraulic interactions between the RMC production wells and the City of Portland (COP) wellfield located west of Fairview Farms.
- **Section 5.2: Fluoride fate and transport.** Discusses general behavior of fluoride in the subsurface (5.2.1) and site-specific fluoride transport, focusing on:
  - Observed fluoride transport processes in silt unit groundwater and in groundwater in the underlying sand units (UGS, intermediate zone, and deep zone). Includes discussion of fluoride concentration trends in the RMC production wells (Section 5.2.2).
  - The potential for soils beneath the soil and debris areas to be a future continued source of fluoride loading to groundwater—that is, the potential for fluoride desorption from soils (Section 5.2.3).
- **Section 5.3:** Summarizes interpretations regarding fluoride migration.

[1] Specifically, formation of fluoride precipitates from dissolved-phase fluoride. High apparent adsorption of fluoride by calcareous soils has been reported in the literature (Rai and Zachara, 1984) and attributed to possible precipitation of the mineral fluorite.

5.1 Groundwater Migration Pathways

Groundwater flow under ambient (nonpumping) conditions is generally from south to north across the site, with groundwater discharging to the Columbia River, as discussed in Section 3.2.1. In addition, shallow groundwater in the easternmost portion of the site may discharge to the Sandy River. The aquifer zones beneath the silt unit respond strongly to diurnal and seasonal fluctuations in the stage of the Columbia River.

The RMC production wells exert strong influences on groundwater flow patterns across most of the site and in all groundwater zones except for the surficial silt unit. Under pumping conditions, vertical hydraulic gradients are predominantly downwards throughout the pumping zone and overlying zones. Under both pumping and nonpumping conditions, groundwater flow in the silt unit is strongly downwards during much of the year, reflecting the influence of precipitation infiltration in the silt unit.

The influence of these flow patterns on fluoride transport in groundwater has been evaluated from long-term groundwater monitoring data, fluoride concentration data, aquifer test analyses, and numerical modeling. These evaluations have indicated that the principal controls on fluoride transport are the RMC production wells and (to a lesser degree) the ambient groundwater flow patterns. The following subsections discuss this control and also describe the interactions between RMC and City of Portland (COP) wellfields and their effect on fluoride transport in groundwater.

5.1.1 Influence of RMC Production Wells

As discussed in Section 4, fluoride is present in groundwater beneath the site at concentrations exceeding its MCL (4 mg/L). The portion of the groundwater system containing fluoride above the MCL is for the most part restricted to onsite areas, including areas north of the U.S. Army Corp of Engineers (COE) flood control dike. A small area of elevated fluoride is present just west and southwest of Company Lake outside of the RMC plant boundary. The portion of the fluoride plume that is present in the intermediate and deep zones appears to be centered around the RMC production wells and is the result of fluoride loading from two principal areas:

- Scrap yard, which is the primary source of the portion of the plume south of the production wells
- Company Lake, which is the primary source of the portion of the plume north of the production wells

The site data suggest that the presence of the fluoride plume in the intermediate and deep zones is attributable to the presence of natural downward gradients from the silt unit and the UGS into the intermediate zone at scrap yard and Company Lake, plus the creation of strong downward gradients from the intermediate zone to the deep zone by pumping of the RMC production wells. In addition, the silt unit is thin at scrap yard and Company Lake compared with the other soil and debris areas in the south plant (south landfill and east potliner).

A sitewide numerical groundwater flow model was developed for the RMC facility. The model is described in detail in *Technical Memorandum No. GW-20: Development of an Updated*

Hydrogeologic Conceptual Model and a Numerical Groundwater Flow Model at RMC-Troutdale (CH2M HILL, In Progress), which documents the construction and calibration of the model and presents the particle-tracking results discussed in this section.

The flow model illustrates how pumping is responsible for the current plume configuration. Figures 5-1 through 5-8 show snapshot views from the model window. These views indicate the traces of "particles" that are initiated at various depths and locations in the model and tracked forward in time to delineate groundwater flow paths. The change in color along the length of a given particle trace illustrates the vertical movement of the particle through the groundwater system. The figures compare the particle traces with the current configuration of the fluoride plumes in groundwater, which are defined by concentrations exceeding the MCL. The figures also compare particle traces under various pumping scenarios for the RMC production wells. Specific observations and conclusions from the figures are as follows:

- Figures 5-1 and 5-2 together show how the configuration of the groundwater plume in the intermediate zone south of the RMC production wells is the result of fluoride migration from the scrap yard soil and debris area. The two figures show the traces of particles that are initiated in the model at the top of the UGS at scrap yard and tracked forward in time. Figure 5-1 presents particle traces under long-term average pumping rates and patterns when the plant is operating, whereas Figure 5-2 shows particle traces under a no-pumping scenario for comparison purposes.[2] Together the figures show that the existing fluoride plume in the intermediate zone conforms closely in shape to the particle traces under the simulated long-term pumping scenario. This observation is consistent with the operational history of the plant; specifically, use of the production wells has occurred continuously for decades (though at varying rates).
- Figures 5-3 shows the traces of particles that are initiated at south landfill and east potliner under the long-term average pumping scenario. The figure shows that the traces from these two soil and debris areas lie primarily outside of the area where the fluoride plume is present in the intermediate zone groundwater. This is consistent with the understanding that these two soil and debris areas are not primary contributors of fluoride to the intermediate zone.
- Figure 5-4 shows the traces of particles that are initiated at south landfill and east potliner for a no-pumping scenario. The flow paths extending from south landfill are perpendicular to the alignment of the intermediate zone plume of fluoride. These traces and the traces from east potliner both extend in a northeasterly direction, which is perpendicular to the flow direction observed at the site under historical pumping conditions.
- Figure 5-5 shows the traces of particles that are initiated at the perimeter of the Company Lake wastewater treatment pond under the long-term average pumping scenario. The traces show that water from the pond recharges groundwater and that groundwater moves radially away from the pond. Particles initiated along the southern

[2] The long-term average pumping scenario consists of a total pumping rate of 1,800 gpm from wells PW03 (320 gpm), PW07 (580 gpm), PW08 (600 gpm), and PW10 (300 gpm). This scenario is based on the average combined pumping rate from January 1990 through October 1991 and on more recent use patterns that have changed the relative pumping contribution from each individual well.

and eastern perimeters of the pond are captured by the production wells. In contrast, particles initiated around the remainder of the pond are beyond the zone of influence of the production wells and therefore discharge to the Columbia River or the Sandy River bar (which extends into the Columbia River from the mouth of the Sandy River).

- The migration of particles from Company Lake towards the production wells indicates that the presence of fluoride in intermediate-zone and deep-zone groundwater between the pond and the production wells arises from fluoride loading from the pond, rather than migration of fluoride from scrap yard to areas near the pond. This is illustrated in Figure 5-6, which shows the combined particle traces from scrap yard and Company Lake under the long-term average pumping scenario.
- Figures 5-7 and 5-8 show particle migration from Company Lake under the no-pumping scenario. Figure 5-7 shows that particles initiated along the northern side of the pond move as they do in the historical pumping scenario (Figure 5-5). However, particle movement from the southern lake perimeter is quite different under no-pumping conditions (Figure 5-8) than under pumping conditions (Figure 5-5). Under no-pumping conditions, particles initiated along the southern lake perimeter move in a northerly direction after migrating into the intermediate zone beneath the lake.

Table 5-1 summarizes groundwater travel times to discharge locations for the flow paths that are illustrated in Figures 5-1 through 5-8.[3] The table shows the following:

- Groundwater travel times from scrap yard to the production wells (under pumping conditions) are between 10 and 15 years, based on the initiation of particles at the geologic contact between the silt unit and the UGS. In contrast, the travel time is substantially longer under no-pumping conditions. This result is partly attributable to the longer groundwater flow paths under non-pumping conditions. However, it is also partly attributable to increases in groundwater velocities in the UGS, the intermediate zone, and the deep zone that arise from pumping of the production wells.
- Travel times at south landfill under pumping and non-pumping conditions are similar to those at scrap yard. For east potliner, which is located closer to the Sandy River than south landfill and scrap yard, the travel times are similar under pumping and non-pumping conditions although the flow paths and discharge locations are different.
- The travel times and discharge points for groundwater at Company Lake vary greatly around the perimeter of the pond under both pumping and non-pumping conditions. For both conditions, travel times are shortest for particles along the north side of the pond, which discharge to the Sandy River and the Sandy River bar over periods of 10 to 15 years. The maximum groundwater travel time to the Columbia River is 30 years under non-pumping conditions, but 60 years under pumping conditions due to enhanced vertical migration that is caused by sitewide water level drawdown induced by the pumping wells. (See Figures 5-5 and 5-8.) Under pumping conditions, travel times from Company Lake to the production wells are as long as 75 years or more based on the substantial lengths of the groundwater flow paths from the pond to the wells. (See Figure 5-5.)

[3] The travel times shown in Table 5-1 are based on an assumption that the effective porosity of the aquifer system is 0.20. Lower effective porosities would decrease the travel times proportionally from those shown in the table.

5.1.2 Evaluation of Influences Between RMC and COP Wellfields

The City of Portland owns and operates the Columbia South Shore Wellfield (CSSW) west of the RMC facility. The portion of the COP wellfield closest to the RMC facility is located approximately 1.5 miles west of the RMC facility and consists of five wells completed in the Blue Lake Aquifer (BLA). (The locations of these wells are shown in Figure 3-3.) On two occasions, water level monitoring data have been obtained that provide insight as to whether the groundwater systems that supply the RMC production wells and the COP wellfield in the BLA are in hydraulic communication.

- During October 1995, a 58.5-hour multiple-well pumping test was conducted at the RMC production wells. During the test, water level data were collected at four of the BLA wells.
- Beginning in late 1995, the City of Portland operated its wellfield (including four BLA wells) to provide an emergency water supply. The average pumping rate during this period was approximately 20,000 gpm, and the pumping lasted for about 27 days. During this period, water level data were collected at Fairview Farms and at the RMC plant site, as well as in the Columbia River, using continuous-recording data loggers.

The principal conclusions from the two tests are as follows:

- The RMC production wells exerted a hydraulic influence as far west as Fairview Farms well FF06 during the October 1995 multi-well test of the RMC production wells. Because the pumping rate during the test was approximately twice as great as the pumping demand under normal operating conditions, it is possible that the magnitude of drawdown and the areal extent over which drawdown occurred were greater than occur during normal operation of the RMC production wells. However, because of the short duration of the test, it is also possible that the test did not overestimate the size of the area where drawdowns occur under long-term pumping from the production wells. (See Section 5.1.2.1 below.)
- Pumping of the BLA wells did not appear to produce a measurable response in either the shallow or deeper portions of the aquifer between the four operating BLA wells and the RMC plant site. This observation suggests that pumping from the BLA wells in the CSSW is unlikely to influence groundwater flow directions beneath the RMC plant site. Conversely, this conclusion also suggests that pumping of RMC wells is unlikely to influence groundwater flow directions in the BLA. (See Section 5.1.2.2 below.)

Observations from these two tests are presented below.

5.1.2.1 RMC Multi-Well Aquifer Test (October 1995)

A constant-rate aquifer test involving pumping all four of RMC's primary groundwater production wells was performed during October 1995. The test is described in detail in Section 5.2.3 of the *Preliminary Conceptual Hydrogeologic Model Report* (CH2M HILL, March 21, 1996).The four wells (PW03, PW07, PW08, and PW10) were pumped at a combined average rate of approximately 2,900 gallons per minute. Data loggers with pressure transducers were installed for measuring water levels in the Columbia River and in 16 shallow and deep observation wells at the site. During the aquifer test, continuous-recording or manual water level measurements were made in 31 onsite shallow groundwater monitoring wells, 11 onsite deep-aquifer production wells, and two offsite deep-aquifer irrigation wells. Continuously recorded water level data were also provided by the City of Portland Water Bureau for four BLA wells (COP well Nos. 12, 13, 18, and 19). Manual water level measurements were collected in four offsite wells located two to three miles southwest of the site (and south of the COP wells). Figure 5-9 shows the locations of the pumping wells and the onsite and offsite observation well networks.

Excess pumped groundwater that was not needed for cooling or for process water was discharged through RMC's supply system to South Ditch, which conveys excess water supply and stormwater to Company Lake for treatment. The aquifer test was prematurely terminated after 58.5 hours of pumping because of a heavy rainfall event, which generated stormwater runoff that raised the water level in the ditch close to a level that could have potentially caused water to overflow from the South Ditch into south wetlands.

The water level data indicated that the RMC production wells exerted a hydraulic influence as far west as Fairview Farms well FF06, approximately 3,000 feet west of Sundial Road (which forms the western boundary of the active plant site). The influence was identified by adjusting water level measurements for trends induced by diurnal stage changes in the Columbia River (due to tidal influences).[4] The pumping influence in Fairview Farms is illustrated in Figure 5-10, which is a distance-drawdown plot for the line of observation wells extending from PW06 west to COP well No. 18. The distance-drawdown plot shows the drawdown that was measured at the end of the pumping period in each well (immediately prior to turning off the pumps). As shown in the figure, less than ½ foot of drawdown was observed at Fairview Farms well FF06, and no drawdown was observed at COP well No. 18.

As discussed in the *Preliminary Conceptual Hydrogeologic Model Report*, the pumping rate for this aquifer test exceeded RMC's average water demand when the plant is at full-production-capacity (1,800 gpm) by approximately 50 percent. Consequently, the report concluded that the hydraulic response of the aquifer to normal operating conditions at the RMC facility is likely to be more limited than was observed in this test. However, the report also recognized that the sustained nature of pumping during plant operations could potentially result in responses at locations that did not respond in this test because of the test's short duration.

5.1.2.2 City of Portland Emergency Pumping (December 1995)

The City of Portland pumped groundwater from the CSSW from November 28, 1995, through December 24, 1995, to replace water supply capacity lost when two water supply lines at the Bull Run Watershed were damaged in a mud slide. Well Nos. 12, 13, 18, and 19, which are constructed in the BLA, pumped at an average rate of approximately 20,000 gpm during this period. Well locations are shown in Figure 5-9. A detailed discussion and analysis of the effect of this event on groundwater east of the BLA is presented in Appendix F.

[4] The adjustments consisted of comparisons of water level trends with the 24-hour moving average of the Columbia River stage. The adjustment also incorporated river efficiency coefficients, which varied from well to well and were based on data logger records collected from early October through November 1, 1995.

Groundwater elevations were monitored in wells around the RMC facility, including Fairview Farms wells FF04 and FF06. Electronic water level measurements were collected using GeoKon® data loggers and pressure transducers and were supplemented with manual measurements. Because groundwater levels are strongly controlled by the Columbia River stage, which fluctuates on an hourly basis due to tidal influences, the electronic data were smoothed by converting raw data for the river stage and the wells to 24-hour moving averages to remove the response to tidal fluctuations. This process also addressed variations that were due to longer-term stage fluctuations, such as precipitation events and fluctuations in Bonneville Dam releases. Because there is a delay between river stage change and aquifer water level response, the Columbia River data was also shifted forward in time to align peaks and troughs in the river and well water level data.

Based on these analysis methods, pumping at the CSSW did not appear to produce a measurable response in either the shallow or deeper portions of the aquifer between the four operating BLA wells and the RMC plant site. This observation suggests that pumping from the BLA wells in the CSSW is unlikely to influence groundwater flow directions beneath the RMC plant site. When joined with the results of the October 1995 test of RMC production wells, this observation also suggests that pumping of RMC wells is unlikely to influence groundwater flow directions in the BLA.

5.2 Fluoride Fate and Transport

This section presents the following information:

- General behavior of fluoride in the subsurface
- Site-specific understanding of fluoride migration that is based on soil sampling, groundwater sampling in monitoring wells, and groundwater sampling in the active production wells and the tap water for the RMC plant
- Quantification of the role of soil adsorption and desorption processes on fluoride loading to groundwater

5.2.1 General Behavior of Fluoride in the Subsurface

The fate of fluoride in the subsurface is governed by adsorption and desorption processes between dissolved-phase fluoride in groundwater and the non-native fluoride that is adsorbed onto soils that form the aquifer matrix. Rai and Zachara (1984) provide an overview of the behavior of fluoride in the subsurface. Studies of fluoride adsorption/desorption indicate that fluoride is not strongly adsorbed by soils; that the maximum adsorption occurs at pH values between about 4.0 and 6.5 and is strongly correlated with the content of amorphous aluminum oxyhydroxides; and that fluoride displaces surface-bound oxyhydroxides during adsorption. Most known fluoride compounds are fairly soluble. Other literature sources (for example, Peek and Volk, 1985; Simard and LaFrance, 1996; and Arnesen and Krogstad, 1998) indicate that adsorption and desorption processes can be described by nonlinear isotherms and that the adsorption process is not fully reversible in most soils.

5.2.2 Site-Specific Data

The fate and transport of fluoride that is present beneath the RMC facility can be assessed by examining soil and groundwater concentration data in silt unit soils and groundwater, as well as fluoride concentration trends in intermediate-zone and deep-zone groundwater.

5.2.2.1 Fluoride in Silt Unit Soils and Groundwater

As discussed in Section 4, fluoride has been detected in soils at elevated concentrations beneath the south plant soil and debris areas. The majority of the elevated concentrations are in the shallow soils overlying the upper gray sand (UGS). Comparisons of the cross sections showing fluoride concentrations in shallow groundwater (Figures 4-9 through 4-14) and in shallow soil (Figures 4-15 through 4-20) indicate the nature of fluoride transport to the UGS from overlying zones. Specific observations are summarized below.

5.2.2.1.1 Scrap Yard. At scrap yard, the soil concentration data indicate that fluoride is present primarily in the debris material and the surficial sand layer that lies beneath the debris and above the silt layer. In the UGS and in all but one silt layer soil sample (the 10-foot sample at GP50, which has a concentration of 2,200 mg/kg), the soil fluoride concentrations are slightly higher than the estimated background concentration[5]. Figure 4-12 shows that fluoride is present in groundwater at elevated concentrations directly beneath the scrap yard in the UGS.

5.2.2.1.2 East Potliner. At east potliner, a greater degree of correlation exists between soil and groundwater concentrations. Specifically, Geoprobe station GP65 shows elevated groundwater concentrations in the silt layer that coincide with elevated soil concentrations at this station and in nearby monitoring well MW11-017. (See Figures 4-11 and 4-17.) Also, samples collected at the top of the UGS at Geoprobe station GP66 show elevated soil and groundwater fluoride concentrations that appear to be responsible for elevated groundwater concentrations at the top of the UGS at GP65. These data together suggest that the soils above and within the UGS could be a continuing source of fluoride to groundwater beneath east potliner.

5.2.2.1.3 South Landfill. At south landfill, good correlation is observed between patterns of elevated soil and groundwater concentrations. (See Figures 4-9 and 4-10 for groundwater and 4-15 and 4-16 for soil.) In particular, Geoprobe station GP59 shows elevated fluoride concentrations in soil and groundwater at depths of 15 and 20 feet below ground surface. These depths coincide with the presence of low-permeability silt. Deeper samples at this station show dramatically lower fluoride concentrations in both soil and groundwater. The transition from elevated concentrations in shallow silt to low concentrations at greater depths coincides with the presence of a geologic contact between the low-permeability silt layer (labeled ML in the figures) and the underlying silty sand materials (labeled SM/ML in the figures).

The presence of elevated fluoride in UGS groundwater at Geoprobe station GP59 appears to result from the presence of fluoride at station GP49, where the silty sand layer separating the silt layer and the UGS is thin. The concentration contrast between the deepest silt layer

[5] The background concentration of fluoride in soil is estimated to be 208 mg/kg, as reported in *Technical Memorandum DS No. 12: Background Data Summary for RMC-Troutdale* (CH2M HILL, December 3, 1996).

groundwater sample (414 mg/L) at GP49 and the UGS groundwater sample at GP59 (61 mg/L) suggests that mixing of fluoride migrating from the silt layer into the UGS results in an approximately 7-fold dilution of the fluoride concentration. The magnitude of this dilution factor is also supported by two independent analyses of the mixing effects and corresponding infiltration rates through the silt unit that would be required in order to achieve this amount of dilution. The two analyses identify similar infiltration rates that would be necessary to create the fluoride distribution shown in Figure 4-9. The two analyses are:

- Calculations of the necessary infiltration rate for a 7-fold dilution factor indicate that the infiltration rate through the silt unit would need to be approximately 0.25 feet/year.[6]
- The magnitudes of the silt unit vertical permeability and vertical hydraulic gradient suggest an infiltration rate of approximately 0.16 feet/year beneath south landfill.[7]

5.2.2.1.4 Summary of Fluoride Migration Patterns in the Silt Unit. The observations described in Sections 5.2.2.1.1 through 5.2.2.1.3 appear to reflect permeability and thickness controls on the migration of fluoride through the silt and the UGS into the intermediate zone. The occurrence of fluoride in the UGS is correlated with the silt unit permeability and inversely correlated with the silt unit thickness. Specifically:

- Laboratory measurements of the silt unit vertical permeability show the silt is more permeable at scrap yard than at east potliner and south landfill. (See Table 3-7.) This is consistent with the presence of fluoride in the UGS and deeper zones. Specifically, the concentration contour maps and groundwater fluoride cross sections presented in Section 4 show substantial fluoride loading to UGS groundwater at scrap yard compared with east potliner and south landfill.
- The silt layer is less thick at scrap yard and east potliner than at south landfill. The groundwater cross sections show that the silt unit is as thin as 6 feet at scrap yard stations GP55 and MW13-022, where elevated fluoride is present in the UGS. At east potliner, the silt layer is also thin, and fluoride is present at elevated concentrations in

[6] This analysis uses a methodology presented in Section 2.5.5 of the publication titled *Soil Screening Guidance: Technical Background Document* (EPA, May 1996, EPA/540/R-95/128). For the aquifer system beneath the RMC facility, this method defines the mixing factor (MF) from the relationship MF = 1+ K*I*d/(I*x), where K is the horizontal hydraulic conductivity of the UGS; i is the horizontal hydraulic gradient within the UGS; d is the mixing zone thickness within the UGS; I is the infiltration rate through the silt unit; and x is the dimension (parallel to the UGS groundwater flow direction) of the area where fluoride loading is occurring. Rearranging this equation to solve for the infiltration rate (I) results in the relationship I = K*I*d / (x*[MF-1]). For south landfill, the estimated values of these parameters are:

- K = 35 feet/day = 12,775 feet/year based on aquifer testing results for the UGS (see Section 3.2.2.1)
- i = 0.0006 feet/foot, as measured from groundwater elevation contour maps in the vicinity of monitoring well MW37-030
- d = 10 feet, which is the thickness from the top of the UGS at GP49 and GP59 to the depth of the 61 mg/L detection at Geoprobe station GP59
- x = 50 feet, which is the distance from GP59 to MW19 (corresponding to a flow path in the northwestern portion of south landfill where fluoride is present in the silt unit at elevated concentrations)
- MF = 7, which equals the highest concentration at the base of the silt unit (414 mg/L at GP49) divided by the highest UGS concentration in the UGS (61 mg/L at GP59)

[7] The vertical permeability of the silt unit was measured as 9.8×10^{-8} cm/sec in a soil sample collected at soil boring SB61. (See Table 3-7.) This permeability may be representative of the silt unit permeability at GP59 but is too low to explain the observed concentration distribution at GP49. A more representative value is 4×10^{-7} cm/sec (which is equivalent to 0.001 feet/day or 0.4 feet/year). This is the average of the SB61 sample and the sample at the highest-permeability location at scrap yard (a 5-foot depth at boring SB11, where the vertical permeability was measured as 2×10^{-6} cm/sec). Vertical hydraulic gradient data for the silt unit at south landfill are not available. Data at scrap yard wells MW02 and MW25 (presented in previous quarterly and annual reports) indicate that the vertical hydraulic gradient at this location is approximately 0.4 feet/foot. Consequently, these data suggest that the silt unit infiltration rate is 0.16 feet/year.

the UGS. In contrast, south landfill shows a thicker silt layer that appears to limit fluoride migration into underlying zones.

5.2.2.2 Fluoride in Production Wells and Deep Monitoring Wells

Fluoride concentrations have been measured since 1990 at the active RMC production wells. During this period, concentrations in tap water inside the plant have ranged from less than 0.5 mg/L to 2.15 mg/L (through February 1999). Since early 1996, an improved understanding of the role of the production wells has been obtained through the continuation of sampling of the production wells, increases in production well use during 1997 and 1998, and groundwater monitoring in two nearby monitoring wells (intermediate-zone monitoring well MW33-095 and deep-zone monitoring well MW33-165). Following is a detailed discussion of the concentration trends that have been observed and how they relate to production well operations.

Figure 5-11 shows fluoride concentration trends from 1996 through early 1999 in the two monitoring wells, the four active production wells (PW03, PW07, PW08, and PW10), and the tap water. (The tap water consists of groundwater from each active production well that is blended prior to the sampling location.) The figure shows that concentrations rose in monitoring wells MW33-095 and MW33-165 during 1997 and peaked in early 1998. Fluoride concentrations have steadily declined in both wells since the peaks were observed in early 1998. A similar pattern has been observed in the production wells and in the tap water, with these peaks lagging the peaks at the monitoring wells by six to nine months. The tap water showed a peak concentration (2.15 mg/L) in August 1998. Peaks in some production wells occurred before August 1998 and some occurred after this date. After peaking in August 1998, the tap water concentration has fluctuated in response to the different timings of peak concentrations in the individual production wells.

Figure 5-12 shows that the general increase in fluoride concentrations in tap water and in the individual production wells has been associated with increased groundwater use that began in early 1998. Groundwater use rose steadily from 1 million gallons per day (mgd) or less prior to 1998 to between 2 and 3 mgd during 1998. The figure also shows that peak concentrations in monitoring wells MW33-095 and MW33-165 coincide with the initiation of pumping at these higher rates during early 1998.

The concentration increases that began in 1997 at the monitoring wells are likely attributable to the initiation of pumping at production well PW07 in April 1997. This production well is located closer than PW03 to the zone of elevated fluoride concentrations in groundwater. The concentration increases during 1998 in the tap water and in the individual production wells is explained by the use of production wells PW05 and PW08, which are both located close to the zone of elevated fluoride and are screened at shallower depths than wells PW03, PW07, and PW10. These observations are shown in Figures 5-13 through 5-17, which compare concentrations in the tap water and in the individual production wells with the pumping rates and patterns in the individual production wells. Together these figures show the following sequence of events from 1996 through 1998:

- During 1996 and through March 1997, pumping occurred primarily from production wells PW03 and PW10. The remaining production wells (PW05, PW07, and PW08) did not operate during this period except for minor uses of PW07. Concentrations were stable during this period in the tap water and in the individual production wells and ranged from about 0.3 to 0.4 mg/L. Total pumping volumes ranged from 0.25 mgd to 1.16 mgd during this period.

- From April 1997 through January 1998, production rates remained generally unchanged (except for a surge in September 1997, when the Fairview Farms aquifer test was conducted). However, beginning in April 1997, pumping shifted from PW03 and PW10 to PW07. This coincided with the beginning of a period of fluoride concentration increases in the monitoring wells (particularly intermediate-zone well MW33-095). Tap water concentrations increased slightly during this period, but remained below 0.5 mg/L.
- Groundwater usage jumped dramatically beginning in February 1998, as operation of the plant's potlines resumed after several years of inactivity. In March 1998, PW05 was activated, and tap water concentrations began to rise. By April 1998, the tap water concentration had increased to 0.85 mg/L. In May 1998, PW05 ceased operation and PW08 began operating steadily and has provided a major portion of the plant's water supply since that time. Over time, PW07 has also become the other primary contributor to the plant's water supply. As these wells became the primary sources of water during 1998, fluoride concentrations rose in the tap water and in PW08 to approximately 2 mg/L.
- A notable decline in fluoride concentrations at the tap and at PW08 occurred during September and October of 1998 when PW03 was reactivated and pumping was reduced at PW07 and PW08. However, this condition lasted only briefly. In November, PW07 and PW08 were reactivated as the primary water supply wells, and concentrations rose to as high as 1.54 mg/L in the tap water. Fluoride concentrations in tap water and in PW08 declined after October 1998 as pumping became more sustained (less cyclic) at PW08 (that is, the well was off for fewer hours each month than during previous periods of heavy use). The fluoride concentration declines in tap water and at PW08 may have resulted from sustained use of PW08, the observed concentration decline at PW03, and/or reductions in fluoride concentrations that were observed immediately upgradient of RMC's production wells (at monitoring wells MW33-095 and MW33-165).

In summary, the fluoride monitoring results and the pumping history together indicate that fluoride concentration trends in individual production wells and in the tap water are directly related to the combined pumping rate of the wellfield, as well as the rate and duration of pumping at individual production wells. The data indicate that increased pumping of the shallowest production wells (PW07 and PW08) during 1997 and early 1998 induced downward migration of fluoride, resulting in higher concentrations in the intermediate-zone and deep-zone monitoring wells at MW33 followed by higher concentrations in the production wells and the tap water. This observation, together with the modeling analyses presented in Section 5.1.1, also indicates that fluoride that moved vertically through the intermediate and deep zones because of production well operations was captured by the production wells.

5.2.3 Quantification of Fluoride Adsorption/Desorption Processes

An evaluation was conducted as to whether soil beneath the soil and debris areas could sustain fluoride concentrations of groundwater exceeding the MCL. This evaluation was conducted because it is possible for desorption of fluoride to occur from soils that contain sorbed concentrations of non-native fluoride (that is, fluoride that has migrated from the soil and debris areas, sorbed onto soils, and is currently present above background levels).

The evaluation was conducted by performing a library search of published literature on fluoride adsorption/desorption mechanics, then using the literature to guide field sampling activities that were conducted as part of the Summer 1998 field program (described in Appendix B). Site soil sampling data and literature data were then correlated to identify isotherm constants describing fluoride desorption. These correlations were used to identify areas where current soil fluoride concentrations are sufficiently elevated that the soils alone could sustain groundwater concentrations exceeding the MCL (irrespective of the concentration of groundwater migrating from an adjoining upgradient area). These results were also used to estimate the degree of reversibility of the fluoride adsorption process (that is, the percentage of the adsorbed fluoride that would be expected to desorb).

The details of this evaluation are described in Appendix G. The main conclusion is that current soil concentrations in the intermediate zone are unlikely to sustain fluoride concentrations above the MCL in groundwater. In the UGS, existing soil concentrations beneath south landfill are also unlikely to sustain fluoride concentrations above the MCL in groundwater. However, soils beneath portions of the scrap yard and east potliner could potentially sustain elevated groundwater concentrations above the MCL. Portions of the silt unit and the overlying surficial sands could also potentially sustain fluoride concentrations above the MCL in all three south plant soil and debris areas. The degree to which elevated groundwater concentrations could be sustained is uncertain because the analysis of the site-specific soil data suggests that the adsorption process is not fully reversible.

In summary, soil concentrations of fluoride in the intermediate zone and in portions of the UGS are sufficiently low that fluoride desorption from these soils is unlikely to sustain groundwater concentrations of fluoride that are as high as the MCL. However, desorption from some UGS soils and some shallower site soils could cause groundwater concentrations to be above the MCL in those soil horizons. Information on the nature and extent of fluoride (presented in Section 4) and the results of the fluoride transport assessment (presented in Appendix G) provide the necessary background to evaluate the effectiveness of remedial alternatives for fluoride in groundwater.

5.3 Summary of Fluoride Migration

A summary of the migration of fluoride in groundwater follows.

1. The principal control on fluoride transport has been the historical use of the RMC production wells. To a lesser degree, ambient groundwater flow patterns have also affected the extent of fluoride in groundwater. As discussed in Section 4, the portion of the fluoride plume that is present in the intermediate and deep zones appears to be centered around the RMC production wells and is the result of fluoride loading from scrap yard and Company Lake. The site data and groundwater flow modeling results

indicate the following specific conclusions regarding the occurrence and migration of fluoride in groundwater:

- Scrap yard and Company Lake contribute fluoride from areas south and north of the production wells, respectively. The presence of fluoride between Company Lake and the production wells is the result of fluoride loading from Company Lake to intermediate-zone groundwater, rather than the result of groundwater migration from the scrap yard past the production wells.
- The presence of the fluoride plume in the intermediate and deep zones is attributable to the presence of natural downward gradients from the silt unit and the UGS into the intermediate zone at scrap yard and Company Lake, plus the creation of strong downward gradients from the intermediate zone to the deep zone by pumping of the RMC production wells. In addition, the silt unit is thin at scrap yard and Company Lake compared with the other soil and debris areas in the south plant (south landfill and east potliner).
- South landfill and east potliner do not appear to be contributing concentrations of fluoride above the MCL to the fluoride plume that is present in the intermediate and deep zones.
- A long-term period of inactivity at the RMC wellfield would cause changes in groundwater flow directions, which in turn would cause changes in fluoride migration patterns. Under such a scenario, groundwater possibly containing fluoride from the three south plant soil and debris areas would migrate in a northerly and northeasterly direction towards the Sandy River and the Sandy River bar (which occupies the Columbia River at the mouth of the Sandy River).
- Groundwater modeling analyses indicate that travel times from scrap yard (in the UGS) to the production wells under historical pumping conditions have been between 10 and 15 years (assuming an effective porosity of 0.20 for the aquifer system). Under a sustained period of no-pumping, the modeling analyses suggest that groundwater travel times from the UGS at scrap yard to the Sandy River would be on the order of 30 to 40 years.

2. Pumping of RMC wells and wells owned by the City of Portland in the Blue Lake Aquifer is unlikely to influence groundwater flow directions on the RMC facility or in the BLA. This is indicated by a multi-well pumping test of the RMC production wells (conducted in 1995) and by a one-month period of sustained pumping (at a rate of about 20,000 gpm) from the BLA in late 1995. Consequently, fluoride beneath the RMC facility is not expected to migrate west towards the BLA due to either RMC or BLA pumping activities.
3. Soil and groundwater concentration data in the silt unit and the UGS indicate that migration of fluoride into the UGS and the intermediate zone is controlled by the permeability and thickness of the silt unit. Specific observations are as follows:
   - The highest soil fluoride concentrations in the silt unit at scrap yard were measured in the surficial debris layer and the underlying sand layer (situated just above the silt horizon) at scrap yard. In the silt horizon, soil concentrations are only slightly higher

than background levels, whereas groundwater concentrations are elevated, which indicates that the silt unit is not a significant contributor of fluoride to groundwater.

- In contrast, at east potliner and south landfill, elevated soil concentrations coincide more closely in location and depth with elevated groundwater concentrations. The distribution of fluoride concentrations in groundwater at south landfill indicates that fluoride concentrations in silt unit groundwater are reduced by a factor of approximately seven upon infiltrating into the underlying UGS.
- The occurrence of fluoride in the UGS is correlated with the silt unit permeability and inversely correlated with the silt unit thickness. Of the three soil and debris areas in the south plant, south landfill shows the lowest concentrations of fluoride in the UGS, the smallest areal extent of fluoride in the UGS, the greatest silt unit thickness, and the lowest vertical permeability that has been measured in site soils (9.8 x 10-8 cm/sec). In contrast, scrap yard shows the highest fluoride concentrations in the UGS, the largest areal extent of fluoride in the UGS, and the thinnest and most permeable silt unit.

4. Fluoride concentration data in the RMC production wells indicate that fluoride concentration trends in individual production wells and in the tap water are directly related to the combined pumping rate of the wellfield, as well as the rates and durations of pumping at individual production wells. The data indicate that increased pumping of the shallowest production wells (PW07 and PW08) during 1997 and early 1998 induced downward migration of fluoride, resulting in higher concentrations in the intermediate-zone and deep-zone monitoring wells at MW33 followed by higher concentrations in the production wells and the tap water. This observation, together with the modeling analyses presented in Section 5.1.1, also indicates that fluoride that moved vertically through the intermediate and deep zones because of production well operations was captured by the production wells.
5. Quantitative evaluations of fluoride adsorption and desorption processes have been performed to identify areas where current soil fluoride concentrations are sufficiently elevated that the soils alone could sustain groundwater concentrations exceeding the MCL (irrespective of the concentration of groundwater migrating from an adjoining upgradient area). The evaluations were based on the findings of published literature and field sampling activities that were conducted as part of the Summer 1998 field program (described in Appendix B). The findings from these evaluations are as follows:
   - The fate of fluoride in the subsurface is governed primarily by adsorption and desorption processes between dissolved-phase fluoride in groundwater and the non-native fluoride that is adsorbed onto soils that form the aquifer matrix. However, literature studies suggest that fluoride is not generally adsorbed strongly by soils and that the soil pH and the concentration of aluminum oxyhydroxides in soil govern the adsorption that does occur.
   - These evaluations indicate that soil concentrations of fluoride in the intermediate zone and in portions of the UGS are sufficiently low that fluoride desorption from these soils is unlikely to sustain groundwater concentrations of fluoride that are as high as the MCL. However, desorption from some UGS soils and some shallower

site soils could cause groundwater concentrations to be above the MCL in those soil horizons. Information on the nature and extent of fluoride (presented in Section 4) and the results of the fluoride transport assessment (presented in Appendix G) provide the necessary background for evaluating the effectiveness of remedial alternatives for fluoride in groundwater.

Table 5-1
Summary of Estimated Groundwater Travel Times from the South Plant Soil and Debris Areas and Company Lake to Groundwater Discharge Locations
Reynolds Metals Company—Troutdale, Oregon

Description of Model Run	South Landfill		Scrap Yard		East Potliner		Company Lake	
	Particle Destination	Travel Time (years)	Particle Destination	Travel Time (years)	Particle Destination	Travel Time (years)	Particle Destination	Travel Time (years)
Historical Pumping [a, b, c]	PW07 and PW08	10-15	PW08	10-15	PW08	25-30	Sandy River and Sandy River Bar	10-20 [d]
							Columbia River	20-60 [e]
							PW03	10-50 [f]
							PW07 and PW08	10-75 or more [g]
No Pumping [b, c]	Sandy River and Sandy River Bar	45-60 (River) 60-80 (Bar)	Sandy River	30-40	Sandy River	20-40	Sandy River and Sandy River Bar	10-15 [d] 20-30 [f]
							Columbia River	20-30 [e]

[a] The total pumping rate is 1800 gpm (2.6 MGD), which is an estimate of the monthly pumping demand when the Troutdale plant is operating at capacity. The pumping is distributed between the wells as follows: 320 gpm at PW03, 580 gpm at PW07, 600 gpm at PW08, and 300 gpm at PW10. For wells PW03 and PW07, all pumping is from a depth interval of approximately 230 to 260 feet, which is represented by layer 9 of the model. For well PW08, 20 percent of the pumping occurs from the deep zone (model layer 7) and 80 percent occurs from model layer 9. All PW10 pumping occurs from the deep gravel zone beneath the site, which is the deepest model layer (layer 11).

[b] Groundwater travel times shown in the table are based on an effective porosity of 0.20 and on the initiation of particles at the top of the upper gray sand (UGS) along the perimeter of each soil and debris area. A smaller effective porosity or initiation of the particles deeper in the UGS would shorten the travel times.

[c] The two model runs together give an indication of the ability of the model to simulate the current distribution of fluoride in groundwater. Neither run by itself provides this indication because of the variability in the historical pumping schedule since the plant began operations.

[d] Particles were initiated along the northern perimeter of the pond.

[e] Particles were initiated along the western perimeter and southwestern perimeter of the pond.

[f] Particles were initiated along the southern perimeter of the pond.

[g] Particles were initiated along the eastern portion of the northern pond perimeter.

SECTION 6

References

SECTION 6

References

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